REPORT

OF THE

Joint Committee on Inductive Interference

TO THE

Railroad Commission of the State of California

Presenting the results of an investigation of inductive interference by power circuits with communication circuits and including rules recommended for the prevention or reduction of such interference

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SAN FRANCISCO, CALIFORNIA
SEPTEMBER 28, 1917

CALIFORNIA STATE PRINTING OFFICE
SACRAMENTO
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INTRODUCTION.

In July, 1914, the California Railroad Commission published the first report of the Joint Committee on Inductive Interference to the Commission and arranged for free distribution of the report to interested engineers and other parties. We then authorized the Committee to continue its work and the present final report is the result.

Complying with requests, not only of the members of the Joint Committee, but also from many other sources, we have decided to publish this final report in the same form as the first report was published. We have also concluded to publish in book form a number of the technical reports of the Joint Committee (see Appendix II of this report), and this publication is now in the course of printing and will be sold at cost by the Commission.

The rules proposed by the Committee have been adopted by the Commission and General Order No. 52, superseding General Order No. 39, "In the Matter of the Construction and Operation of Power and Communication Lines for the Prevention or Mitigation of Inductive Interference," effective August 1, 1918, has been issued.

The task of the Joint Committee is now completed. The Commission's appreciation of the work done was expressed in a letter of November 14, 1917, to the individual members of the Committee, reading in part as follows:

> "We acknowledge receipt of final report of the Joint Committee on Inductive Interference, dated September 28, 1917.
>
> In receiving this final report and in accepting the resignations of the members of the Joint Committee, we desire to express to each member of the Committee our very sincere appreciation for the splendid work which the Joint Committee has done during the last five years.
>
> The work in its complete form is a monument to this Committee of which each member must be justly proud.
>
> The Railroad Commission will give prompt consideration to the recommendations of the Joint Committee with reference to certain changes in General Order No. 39. The Commission is also taking up the question of the publication in book form of a number of the technical reports of the Joint Committee.
>
> As soon as the matter of the publication of the book has been finally determined upon, the Railroad Commission will also publish in pamphlet form the Joint Committee's final report.
>
> The Commission is asking the Chairman of the Joint Committee to make the necessary arrangements so that the records and correspondence files of the Joint Committee may be transmitted to the Railroad Commission for permanent custody."

Since the date of that letter the value of the labor accomplished by the Joint Committee has become even more apparent, and we take this occasion to express again our sincere appreciation.

CALIFORNIA RAILROAD COMMISSION.

E. O. EDGERTON,
H. D. LOVELAND,
ALEX GORDON,
FRANK R. DEVLIN,
Commissioners.

San Francisco, California,
September 13, 1918.

LETTER OF TRANSMITTAL.

September 28, 1917.

To the Railroad Commission of the State of California:

GENTLEMEN: Nearly five years ago the Joint Committee on Inductive Interference was organized under the auspices of the Railroad Commission of the State of California and began its investigations with the object of developing a better understanding of the subject of inductive interference and particularly of acquiring information necessary for establishing regulations which could be accepted by all interests concerned as being effective, comprehensive and reasonable.

In July, 1914, the Joint Committee rendered to the Railroad Commission a preliminary report containing an account of its investigations up to that time and including provisional rules which were recommended for immediate adoption. These rules were approved and are embodied in your General Order No. 39, which is now in effect in California.

In its preliminary report the Joint Committee outlined further investigations which it seemed important to make preparatory to putting the rules into more permanent shape and asked your authorization to carry on these investigations. This request being approved, the work was resumed and much additional information has since been obtained. The past few months have been devoted to the preparation of a report outlining briefly the main features of all work done by the Joint Committee. This report, which is submitted herewith, contains a draft of revised rules which are believed to represent a substantial improvement over the rules contained in the 1914 report. The Joint Committee recommends that these revised rules be approved by the Railroad Commission and issued as a new order to supersede General Order No. 39.

An attempt was made to meet the urgent demand for information defining the limiting relationships between power and communication lines which constitute a parallel. It was found, however, that sufficient information was not at hand to satisfy all parties as to a basis upon which these relationships could be set forth definitely.

While the subject of inductive interference offers an almost inexhaustible field for further investigation, the Joint Committee feels that the object for which it was formed has now been substantially accomplished and it seems unnecessary that its work should be further prolonged. The rules recommended will constitute, it is hoped, a satisfactory basis of procedure for several years at least, in dealing with cases of inductive interference, assuming a proper spirit of co-operation among the companies concerned. The rules themselves definitely call for and emphasize the necessity for this co-operation. In course of time, no doubt, the experience gained in the application of these rules, together with advances in the art, will make it desirable that the rules be changed in some respects, but such changes are thought to be a matter of the more or less distant future and not to require the continuance of the Joint Committee.

From time to time during the course of this investigation Technical Reports have been prepared setting forth in detail the matters which have been studied and the results and conclusions derived. There are in all 71 of these Technical Reports which are listed in Appendix II of the report herewith transmitted. As they contain a large amount of valuable information and are in fact the only records of most of the data derived by the Joint Committee, it is particularly important that they be rendered available to persons interested. To this end, the Joint Committee has selected 30 of the most valuable of these Technical Reports and earnestly recommends to the Railroad Commission that these be printed in a suitable volume by the State of California and offered for sale to libraries, colleges, companies, societies and individuals interested. The reports recommended for publication are so designated in the list given in Appendix II.

The official copies of the Technical Reports, other original records, and the correspondence files of the Committee are ready to be placed in the custody of the Commission.

In transmitting this report, which marks the conclusion of its work, the Joint Committee desires to express its satisfaction at the degree of success which has been reached in composing the differences formerly existing in California between the power and communication interests, differences due principally to lack of familiarity with the physical aspects of this subject. While it would be too much to say that there is now complete unanimity of opinion on every feature, still the Joint Committee has been able, after careful consideration of all information available, to agree unanimously upon the present report. In the opinion of the Committee the results accomplished emphasize strongly the superiority of a co-operative investigation of this kind, whereby the fundamental facts are ascertained and acted upon, as compared with litigation or other methods of arbitrary settlement without the benefits derived from such investigation.

In conclusion, the Joint Committee takes pleasure in acknowledging that the credit for what has been accomplished is due primarily to the Railroad Commission of the State of California which has consistently held to the policy of a co-operative investigation and has cordially supported this Committee in its work.

Respectfully submitted.

(Signed)

A. H. Griswold,
H. A. Barre,
J. E. Woodbridge,
J. L. Ord,
V. V. Stevenson,
R. W. Mastick,
Howard S. Warren,
C. H. Temple,
James T. Shaw,
Richard Sachse,
F. Emerson Hoar,
Arthur F. Bridge,
A. L. Wilson,
John A. Koontz,
J. P. Jollyman,
P. M. Downing,
A. H. Babcock.

FINAL REPORT

OF THE

Joint Committee on Inductive Interference to the Railroad Commission of the State of California

INTRODUCTION.

This report embodies the results of an investigation by the Joint Committee on Inductive Interference, extending over a period of approximately four years. The task undertaken by this Committee was a study of the problem of interference with communication (signal) circuits caused by the inductive effects of neighboring power (electrical supply) circuits, including field experiments and tests necessary to determine the underlying physical facts, and the preparation of recommendations to the Railroad Commission of the State of California for its guidance in making rulings designed to prevent or mitigate such interference.

A previous report by this Committee to the Railroad Commission was rendered on July 7, 1914, embodying the results of the first two years of the investigation and including provisional rules for the prevention or mitigation of inductive interference, based on the information available at that time. The rules therein recommended were adopted by the Railroad Commission in its General Order No. 39, effective August 20, 1914. The previous report also contains an outline of further investigations which this Committee considered essential in order that additional information might be acquired for amplifying and revising the rules to make them more definite and complete. These further investigations have now been carried out, as far as practicable, and certain additional work directed toward the same end has also been done.

Having completed the field investigations and having carefully analyzed and studied all information accumulated, the Committee now presents its final report, including revised rules for preventing or reducing inductive interference. The new rules are not radically different in substance from the rules formerly recommended and now in effect in California, but are considerably changed in form and arrangement. They are more specific as to certain of the requirements, more complete in several respects, less arbitrary in setting physical limits to be observed, more clearly expressed and, it is believed, better adapted to the conditions of practical use.

This report, which contains an account of the Committee's work from the beginning, including that covered by the preliminary report, is divided, for convenience, into three parts as follows:

Part One gives a historical account of the Committee's formation and activities.

Part Two presents, in nontechnical language, so far as possible, the nature of the subject, a brief resumé of the principal facts established or agreed upon by the Committee, and a concise statement of the physical principles underlying preventive or remedial measures.

Part Three contains the Committee's final recommendations for rules, together with explanations of the same in detail.

PART ONE.

HISTORY OF COMMITTEE'S ORGANIZATION AND WORK.

Formation of Committee.

The formation of the Joint Committee on Inductive Interference was the outgrowth of certain differences involving power, communication and railroad interests which were brought to the attention of the Railroad Commission of the State of California. As an alternative to contesting the issue at that time it was agreed by the power and communication companies, with the approval of the Commission, that a joint investigation should be made to obtain certain information essential to a proper solution of the difficulties due to inductive interference. The Commission desired that the matter be thoroughly investigated before passing upon the general principles involved in these difficulties. To this end a general conference was called to select representatives to form a "Joint Committee" empowered to conduct tests, experiments, and investigations, the results of which would serve as a basis of recommendations for rules and regulations to be issued by the Commission, tending to minimize inductive interference and physical hazard arising from parallelism of different classes of circuits. This conference was held December 16, 1912. As a result the Joint Committee on Inductive Interference, representing the Railroad Commission and railroad, power and communication interests of the state, was organized and authorized by the Commission to conduct the desired investigation.

Personnel.

The personnel of the Committee selected is given below.

Representing the Railroad Commission:

Mr. R. A. Thompson, Chief Engineer.
Mr. A. R. Kelley, Assistant Engineer.
Mr. James T. Shaw, Assistant Rate Expert.
Mr. F. Emerson Hoar, Assistant Rate Expert.

Representing Railroad Interests:

Mr. A. H. Babcock, Consulting Electrical Engineer, Southern Pacific Company.

Representing Telephone and Telegraph Interests:

Mr. A. H. Griswold, Plant Engineer, The Pacific Telephone and Telegraph Company.
Mr. R. W. Gray, Division Superintendent, Western Union Telegraph Company.
Mr. C. H. Temple, General Manager, United States Long Distance Telephone Company.
Mr. L. M. Ellis, General Manager, Union Home Telephone Company.

Representing Power Interests:

Mr. H. A. Barre, Electrical Engineer, Pacific Light and Power Corporation.
Mr. Louis Elliott, Engineer, Great Western Power Company.
Mr. P. M. Downing, Engineer, Pacific Gas and Electric Company.
Mr. J. E. Woodbridge, Chief Engineer, Sierra and San Francisco Power Company.

Since the formation of the Committee, through additions, resignation or death, the personnel of the Committee has changed as follows:

Mr. Louis Elliott resigned and Mr. J. A. Koontz, Engineer of the Great Western Power Company, was appointed in his place.

Mr. V. V. Stevenson, Electrical Engineer of the Postal Telegraph-Cable Company, and Mr. L. N. Peart, General Superintendent of the San Joaquin Light and Power Company, were added to the original membership by action of the Committee.

Mr. R. A. Thompson, Chairman of the Joint Committee, resigned. Mr. W. C. Earle, his successor as Chief Engineer of the Commission, was elected to membership and chairmanship. Subsequently Mr. Earle resigned and Mr. Richard Sachse, who succeeded Mr. Earle as Chief Engineer of the Railroad Commission, was elected a member and Chairman of the Committee.

Mr. L. M. Ellis resigned and Mr. R. W. Mastick, Transmission and Protection Engineer of the Pacific Telephone and Telegraph Company, was elected to membership.

Mr. H. S. Warren, Electrical Engineer of the American Telephone and Telegraph Company, was elected to honorary membership.

Mr. James T. Shaw, Secretary of the Joint Committee, resigned. Mr. A. R. Kelley was elected to the office of Secretary. The vacancy in membership created by the resignation of Mr. Shaw was later filled by the election of Mr. A. L. Wilson, Assistant Rate Expert of the Railroad Commission. Mr. James T. Shaw was elected to honorary membership.

The death of Mr. L. N. Peart created a vacancy which was filled by the election of Mr. J. P. Jollyman, Engineer of Electrical Construction of the Pacific Gas and Electric Company.

Mr. A. R. Kelley resigned, and Mr. A. F. Bridge, Assistant Electrical Engineer of the Railroad Commission, was elected to membership and to the office of Secretary.

Mr. R. W. Gray resigned and Mr. J. L. Ord, Division Plant Superintendent of the Western Union Telegraph Company, was elected to membership.

Organization.

The organization and personnel of the Joint Committee on Inductive Interference were approved by the Railroad Commission on January 6, 1913, and the Committee thereupon proceeded with its tests and investigations.

For the more efficient conduct of its work the Joint Committee was divided into several subcommittees, each assigned to and responsible for certain branches of the investigation. The present organization of the Committee is given on a chart presented as Appendix V.

Early in its work the Committee established a field engineering staff, reporting to the Subcommittee on Tests, to conduct the necessary tests and investigations. This field staff was at first composed of engineers in the employ of The Pacific Telephone and Telegraph Company and the American Telephone and Telegraph Company, and was later augmented by the addition of two engineers and a stenographer, engaged by the Committee. Since August, 1914, the stenographer has been provided by the Railroad Commission. In November, 1914, a third engineer was

engaged by the Committee and three were retained in its employ for nearly a year.

The Committee wishes to express its appreciation of the able manner in which Mr. L. P. Ferris has supervised the analytical and theoretical work.

Investigations.

Previous to the formation of the Joint Committee in December, 1912, The Pacific Telephone and Telegraph Company had started an investigation of inductive interference between the lines of the Coast Counties Gas and Electric Company and the lines of the telephone company in the neighborhood of Morgan Hill in Santa Clara County. This investigation was completed by the Committee and its results have been considered in connection with other work carried out by the Committee.

In January, 1913, the Committee established its field staff at Salinas, to investigate parallels on the line of the Sierra and San Francisco Power Company north of Salinas and on the line of the Coast Valleys Gas and Electric Company south of Salinas, both of these power lines being parallel with the lines of The Pacific Telephone and Telegraph Company, the Western Union Telegraph Company and the Southern Pacific Company's signalling system. The investigation at Salinas continued from January, 1913, until July, 1913.

The work undertaken at Salinas was for the purpose of determining (1) the magnitude and characteristics of the induction produced in the communication circuits, the factors in the power circuit causing this induction and the quantitative relationships involved; and (2) the effect of the condition of the neutral (grounded or nongrounded) of the autotransformers at Salinas, on the induction in the communication circuits.

Tests were made of the induction in the communication circuits, both north and south of Salinas, under operating conditions of the power circuits and with the neutral at Salinas alternatively grounded and nongrounded. Tests were also made with special methods of energizing the power circuit, in order to determine the relative importance of various factors in causing the induction. This determination was also made by theoretical methods, by computation of induction based upon the dimensions of the parallel involved, and the results compared with those of the tests. Instrument transformer equipment was investigated in order to determine the errors thereby introduced in measurements of the power-circuit voltages and currents.

In July, 1913, the field headquarters were moved to Santa Cruz. At this point the Committee desired to test the relative merits of various schemes of transpositions* for both power and telephone circuits, and to complete the investigation begun at Morgan Hill on the system of the Coast Counties Gas and Electric Company, which system is of a different character from that studied at Salinas. A mathematical study of transpositions in general, and particularly of those for the parallel between Santa Cruz and Watsonville was completed.

During the time the field headquarters of the Committee were at Santa Cruz, the report of the Committee to the Railroad Commission,

*For definition of "transposition" see page 32.

dated July 7, 1914, was presented. This report contained an account of the formation of the Committee, its activities and the results accomplished up to that date, and also included such recommendations for rulings by the Railroad Commission, as seemed justified to the Committee at that time. In addition, there was given a program of future work designed to put the Committee in possession of information which would permit making the recommended rulings more definite and complete.

In a letter of acknowledgment to the Committee the Railroad Commission approved the program of future work which was laid down in the report and authorized the continuance of the Committee's investigations. This program comprised experimental studies both of transpositions and of residual* voltages and currents of power circuits. The study of transpositions included: (1) the determination of the practical effectiveness, in reducing induction, of systems of power and communication circuit transpositions properly co-ordinated with each other, with consideration of different lengths of balanced sections; (2) the influence of imperfect electrical balance of communication circuits in impairing the effectiveness of transposition systems, and (3) practical effectiveness of transpositions in a power circuit isolated from ground in balancing the voltages between the several conductors and ground, with consideration of the relative efficiency of barrels** of different lengths.

The study of residual voltages and currents included an experimental investigation of different types of power system connections and apparatus with respect to the production of residual voltages and currents, of means to be employed to limit their magnitudes and the determination of the minimum values which will produce harmful inductive interference.

The work outlined in this program was continued at Santa Cruz until November 24, 1914. The experimental study of the effectiveness of transpositions in power and communication circuits undertaken at this point could not be carried out, due to lack of suitable equipment. An investigation of the effect of various transformer connections and of the magnetic density employed in transformer iron on the residual voltages and currents introduced in grounded-neutral networks by such transformers was begun. In addition, from Santa Cruz as headquarters, measurements were made with portable apparatus at various points on the systems of the Coast Counties Gas and Electric Company, the Sierra and San Francisco Power Company, and the Pacific Gas and Electric Company in order to study their characteristics with respect to residual voltages and currents.

On November 24, 1914, the field headquarters and laboratory of the Committee were moved to San Fernando. This location offered a number of advantages for experimental work, the chief one being the presence of an unused thirty-seven mile 15,000-volt line of the Pacific Light and Power Corporation which was available for testing at all times. A telephone circuit carried on the same poles with the 15,000-volt circuit was also available, constituting a parallel for experimental purposes. In addition, transformers were loaned by the Pacific Light and Power Corporation which, with other transformers already pro-

*For definition of "residual" see page 33.
**For definition of "barrel" see page 32.

vided by the Sierra and San Francisco Power Company, gave opportunity for carrying out transformer studies.

The principal experimental work undertaken at San Fernando comprised studies of the factors affecting the residual voltages and currents of power circuits, the effectiveness of transpositions in balancing power circuits and in neutralizing inductive effects, and the magnitude of inductive effects in short, uniform, nontransposed sections of parallel. Concerning the residual voltages and currents of power circuits isolated from ground, the investigations included the effects of transpositions, leakage, accidental grounds and frequency of alternations. Concerning the residuals of grounded-neutral circuits the investigation included the effects of magnetic density of the transformers and of various connections of the transformer banks. In preparing for the latter study a difficulty was encountered, due to large double-frequency residual voltages and currents, apparently peculiar phenomena previously unrecorded and probably of rare occurrence in practice. These were investigated to a very limited extent, for the purpose of devising means to overcome them so that the programmed tests might be carried out.

The availability of both an idle power circuit and an idle telephone circuit, the conditions of which could be varied for experimental purposes, gave an excellent opportunity for studying induction and the effect thereon of both power and telephone circuit transpositions and of telephone circuit unbalances. An extensive series of tests was made to determine the ratios of induced voltage in the telephone circuit to inducing voltage or current in the power circuit under different conditions of operation of the power circuit, for a short, uniform, nontransposed section of parallel. These ratios, termed coefficients of induction, were also obtained independently by calculations based upon physical dimensions of the line. The results of the two independent determinations were compared to ascertain the practicability of obtaining coefficients of induction for other cases by computations thereby eliminating the necessity for tests. Advantage was taken of the opportunity at San Fernando to measure the residual voltages and currents of the Pacific Light and Power Corporation's 15,000-volt system to supplement the similar measurements previously made on other systems.

On June 17, 1915, the headquarters of the field staff were moved to San Francisco, where the work of analyzing the San Fernando data was completed. At San Fernando the Committee's energies were largely centered on completing the experimental work, before the power line was required for service.

It was endeavored to make the analyses and reports as thorough and complete as possible. For each of the subjects experimentally investigated at San Fernando, theoretical studies were undertaken at San Francisco, which in some cases were much extended in scope over that of the corresponding experimental work. Where possible, the experimental and theoretical results were compared. The effects of circuit configuration, or arrangement and relative location of conductors, transpositions and frequency on the residual voltages and currents due

to the line unbalance of power circuits isolated from ground, and the effects of accidental grounds, were investigated from a theoretical standpoint. A study was made of the relation of magnetic density of the transformer iron and of transformer connections to the residual voltages and currents of triple frequencies thereby introduced into connected circuits. A report was prepared giving formulas for the computation of coefficients of induction in communication circuits paralleled by power circuits, including an explanation of the derivation of the formulas and convenient forms which had been developed for systematically carrying out such computations.

To determine the effect of configuration and relative position of power and communication circuits on the induction in the latter, an extensive series of computations based upon the dimensions of assumed cases of parallelism, was carried out. The results of this study comprise 214 curve sheets, containing over 3,000 curves, by the aid of which the values of the coefficients of induction for those cases of parallelism which occur most commonly may be determined.

Among the important reports prepared at San Francisco is one reviewing previous work and presenting new data on the subject of co-ordinating power-circuit and telephone-circuit transpositions as a means of reducing interference. A new telephone transposition system developed by the American Telephone and Telegraph Company, largely in response to the need for a system of telephone transpositions having increased flexibility in respect to co-ordination with power-circuit transpositions, is described and its use illustrated. As examples of co-ordinated transposition systems, plans are presented for all the parallels which have been experimentally investigated by the Committee.

Apparatus suitable for use in the experimental work of the Committee was not easily obtainable and in many instances it was necessary to design and develop special apparatus for certain of the tests. In cases where apparatus was not available for measuring desired quantities directly, it was necessary to develop methods of measurement whereby they might be obtained indirectly.

In deciding from time to time upon its program for future work, the Committee has found it necessary to formulate and consider in detail many plans of experimentation which have never been carried out. It has not always been easy to decide upon the best location for carrying on a particular investigation when each of the several different possible locations possessed certain advantages. To decide between them or to choose between different programs of work has meant that the several plans under consideration had to be worked up in considerable detail before the preponderance of advantage in favor of some one procedure could be established. In several cases plans for work regarded as particularly desirable had to be given up because they were found to be too laborious, or for other reasons were not feasible.

In the course of the investigation seventy-one Technical Reports have been prepared, which describe in detail the various features of the work, the method and apparatus employed and the results accomplished. These reports, some of which are recommended for publication, are listed in Appendix II.

At the request of the Committee, laboratory investigations were made in New York by the American Telephone and Telegraph Company, the Postal Telegraph-Cable Company and the Western Union Telegraph Company to determine the detrimental effects of extraneously induced currents on the operation of telephone and telegraph circuits. Reports of the results of these investigations were submitted to the Committee. These are also listed in Appendix II.

At various times during the course of its work, the Committee has contributed discussions before the American Institute of Electrical Engineers. The Committee's report of July 7, 1914, was presented at the Spokane Convention of the Institute in September, 1914, and later at meetings of the San Francisco and of the Los Angeles sections of the Institute. On each of these occasions considerable discussion was brought forth. In June, 1915, at the Deer Park Convention in connection with papers presented on the subject of irregular power-circuit wave-forms, the Committee submitted a discussion from the standpoint of inductive interference. In September, 1915, at the Panama-Pacific Convention the Committee submitted a discussion in which the progress of the work from July, 1914, to September, 1915, was described. In September, 1916, at the convention of the Institute held in Seattle, the Committee submitted a discussion of a paper presented on the subject of irregular wave-forms.

Finances.

The funds required for carrying on the work of the Committee were contributed by various telephone, power and telegraph companies. Such contributions were made at the start of the investigation and immediately after the report rendered to the Commission on July 7, 1914. Further support was given in the furnishing, by the railroad companies, of free transportation to the Committee members and employees while on Committee business, and of the Committee's equipment; by the telephone companies of the services of their engineers on the work of the field staff; and by the Railroad Commission of the stenographer and stationery supplies. The time which the Committee members devoted to the work was without cost to the Committee.

It is estimated that the total cost of the investigation is more than $100,000.

PART TWO.

EXPLANATION OF PROBLEM AND SUMMARY OF RESULTS.

Nature of subject.

The object sought herein is to describe what inductive interference is, using as far as practicable nontechnical terms, for the benefit of those not familiar with electrical theory.

The transmission of power electrically by wire circuits in either large or small quantities requires a *current* of electricity. Also, to make electricity flow, there must be in the circuit a *voltage* or, in other words, electric pressure, as all circuits offer more or less resistance or impedance to an electric current. If the voltage is produced directly by a battery it forces the electric current around the circuit in one direction only. Such current is called *direct* or *continuous*. Continuous voltage and current may also be produced by an electric generator, and this is the common practice for street railways, but on most other power lines the generators produce an *alternating* voltage,—that is a voltage which during each short interval of time known as a *period* (usually not longer than one twenty-fifth of a second) varies in value from zero up to a maximum, then diminishes to zero, increases to a maximum in the opposite direction, and then diminishes again to zero, repeating this cycle of variations through succeeding equal periods. Thus, the voltage and the corresponding current change in direction or alternate twice each period. The number of periods or cycles per second is called the frequency.

The voltage associated with any electric circuit is accompanied by an electric field of force, or condition of stress, in the surrounding space, whose intensity is proportional to the voltage. At the same time the corresponding electric current is accompanied by a magnetic field of force which occupies the same surrounding space and whose intensity is proportional to the current. Thus any changes in the magnitude or direction of the voltage and current, such as the alternations described above, are accompanied by corresponding changes in their fields. The intensity of these fields of force, in general, diminishes very rapidly with increasing distance from the circuit.

Conversely, any other circuit within these fields of force will have voltages and currents set up or "induced" in it, when changes occur in the fields, that is, when the voltage or current of the first circuit changes. Power circuits of the alternating-current type, most commonly employed in power transmission, having their voltages and currents continually varying, will continually induce voltages and currents in a neighboring communication circuit. These induced voltages and currents are evidence of the absorption of energy from the fields. Thus one circuit influences another by the transfer of energy from the one to the other, without any contact between the wires of the two circuits. This phenomenon, termed "induction," has long been known, and has many useful applications in electrical engineering.

To transmit signals over a communication circuit it is necessary that the power used, and thus the voltage and current, vary from instant to instant. In telephone circuits this variation is extremely complex, the

current which reproduces the human voice in a distant telephone consisting of a number of component simple currents varying in frequency from about 100 to 4,000 cycles per second. For telegraph circuits the variation is much less complex and the frequencies of the important components of the voltage and current are less than 300 cycles per second. In both cases the signalling impulses are sent and received by delicate mechanisms, and the amounts of power required are exceedingly small, particularly for telephone circuits. When communication circuits are in the field of influence of a power circuit the rate at which energy is transferred to them by induction may be comparable with, or even larger than, the power required for their operation, although entirely inappreciable compared to that of the power circuit. For example, the power required to operate a small incandescent lamp is sufficient, if directly applied, to cause a loud noise in several million telephone receivers.

For power circuits of the type most commonly used in California, the frequency is either 50 or 60 cycles per second. This is the fundamental frequency of the voltage and current, representing useful power, but there are also present in power circuits other voltages and currents, usually of relatively small magnitude, of various higher frequencies up to several hundred cycles per second. These higher frequencies or *harmonics* of the fundamental frequency, are the chief cause of interference to telephone circuits, since they are of the frequencies of the sound-waves of the human voice, at which the telephone is most sensitive. On the other hand, the chief interference with telegraph circuits is caused by the fundamental or useful frequency of the power circuits, which most nearly corresponds to the frequency of the telegraphic impulses.

The disturbances thus caused in telephone circuits manifest themselves as humming noises which impair the intelligibility of conversation and cause annoyance. In telegraph circuits, chattering of the relays is caused, the intelligibility of signals is impaired, and the speed and ease of transmission are reduced.

Under abnormal conditions the inductive disturbance due to a power circuit may be very greatly increased. When sudden changes take place in the conditions of the power circuit such as those caused by energizing or de-energizing the circuit, or when a wire breaks and falls to ground, relatively large amounts of energy may be suddenly introduced into the communication circuits. These momentary impulses may be sufficient to constitute a physical hazard, to operate protective devices or to cause severe acoustic shocks to telephone operators or users.

Briefly, then, inductive interference may be defined as the impairment of the serviceability of communication circuits resulting from the transference of energy into them, through intervening space, from near-by power circuits. The study of inductive interference deals with the factors affecting the magnitude and character of the induction and their relationships, the attendant detrimental effects on communication circuits and the means to be employed in overcoming or mitigating such interference.

Summary of facts established.

It seems desirable to summarize briefly the principal technical facts regarding inductive interference, which may now be considered as established. Only the most important points are mentioned here, a detailed technical discussion being given in the Technical Reports.*

1. *Primary Cause.*

As previously shown in discussing the "Nature of Subject," the primary cause of inductive interference is the presence, about the power circuits, of fields of influence which vary in intensity from instant to instant, usually in periodic or cyclic fashion. Communication circuits in regions where these fields are of appreciable strength absorb energy therefrom, by "induction." When the rate at which the energy is thus absorbed is of the same order of magnitude as the power required for the transmission of signals, the impulses received at the terminals of the communication circuit are distorted and the serviceability of the circuit is impaired.

2. *Interference to Telephone Circuits—Harmonics.*

Under normal operating conditions of the disturbing power circuits, interference to telephone circuits, manifested by a humming noise from the telephone receivers, is due almost entirely to the higher harmonics of the power-circuit voltages and currents; for the reason that such harmonics cover a considerable portion of the range of frequencies of human speech, at which telephone apparatus is most sensitive. Except when the interference is very slight or very severe, the detrimental effect of extraneous current in a telephone receiver increases approximately in direct proportion to the magnitude of the current. Increasing the frequency causes a very rapid increase in the detrimental effect (roughly as the square of the frequency) up to about 800 periods per second, beyond which there is a gradual decrease. When several frequencies are present in the extraneous current, the resultant detrimental effect is considered roughly proportional to the square root of the sum of the squares of the separate effects of the several single-frequency components, though this relation has not been definitely established.

The higher harmonics, which are irregularities of the voltage and current waves of power circuits, usually result from:

(*a*) design and construction of generators and motors, whereby pure sine wave shapes are only approximated;

(*b*) the use of iron in transformers under conditions approaching magnetic saturation, thereby causing distortion of the current and voltage waves;

(*c*) the presence of electric arcs in the circuit, as in some street-lighting systems.

The higher harmonics which commonly occur in alternating-current systems are odd integral multiples of the fundamental frequency. They are of sufficient magnitude to be of importance, often as high as nineteen times the fundamental frequency, and have been observed as

*Listed in Appendix II.

high as the 35th order. High frequency voltages and currents also occur in direct-current systems. Harmonics (other than the fundamental or first harmonic) are not essential to the functioning of power systems and may be sources of trouble therein.

Induction of the fundamental frequency of power circuits (below 100 cycles per second) is the cause of very little interference to telephone circuits, except when its magnitude is sufficient to constitute a physical hazard, or to operate grounded signalling devices, as both the human ear and telephone apparatus are much less sensitive to these relatively low frequencies.

3. *Interference to Telegraph Circuits.*

Under normal operating conditions of the disturbing power circuits, interference to telegraph circuits, manifested by the reduction in clearness and maximum speed of signalling, is due to induced currents of fundamental frequency and, to a limited extent, frequencies of the lower harmonics (chiefly the third).

Telegraph receiving instruments are readily responsive to these frequencies, because they approach the normal operating frequencies of telegraph transmission. Telegraph instruments are not sensitive to the higher harmonics. Other signal circuits (telephone circuits excluded), in general, resemble telegraph circuits in being most affected by induced currents of fundamental frequency.

4. *Balanced and Residual Components.*

In analyzing inductive effects, it is convenient to divide the power-circuit voltages and currents into two general classes: (1) "balanced," with respect to the earth as a neutral conductor or point of reference, and, (2) "residual," completely unbalanced with respect to the earth, *i.e.,* employing the metallic power-circuit conductors, as a group, for one "side" and the earth as the other side of their circuit.

"Balanced" current components in the several conductors of a power circuit are such that at every instant their algebraic sum is zero. The algebraic sum of the total currents in the several conductors of a power circuit at any instant is the "residual" current. Similarly, the "balanced" voltages of the several conductors are such that their algebraic sum is zero at every instant, while the algebraic sum of the total voltages to ground at any instant is the "residual" voltage.

As an example, a trolley circuit, consisting of an overhead trolley wire and "return" through rails and earth, is completely unbalanced with respect to the earth, its total voltage and current being residual. On the other hand, a two-wire circuit having no metallic connection to earth and its two sides symmetrical with respect to the earth's surface and not in close proximity to other circuits or objects, would have no residuals, the voltages to earth of the sides of the circuit being equal and opposite and the currents wholly confined to the metallic conductors and therefore equal and opposite, *i.e.,* in both cases balanced.

This classification of the voltages and currents is of basic importance, since there is no generally applicable relation between balanced and residual components or their inductive effects, and furthermore since the remedies for induction from balanced and residual voltages or currents are often fundamentally different.

The circuits commonly employed in power transmission and distribution ordinarily have both classes of voltages and currents in sufficient magnitude to require attention. With exceptions, such as trolley circuits above mentioned, the balanced components of fundamental frequency are the useful energy-transferring agents, while the residuals are the result of incidental differences between ideal design and construction of line and apparatus, giving perfect balance, and design and construction which approach this condition sufficiently for commercial operation, disregarding inductive effects.

Both balanced and residual voltages and currents contain harmonics, but the general tendency is that the residuals contain greater percentages of harmonics than do the balanced components. Besides, under some conditions (discussed in 5 below), a series of harmonics, odd multiples of three times the fundamental frequency, appear as residuals, but not in the balanced components.

Inductive effects from residuals are usually of greater intensity than those from balanced voltages or currents of equal magnitude. The ratio of effects from these two sources is exceedingly variable, ranging from about two to several thousand. The relatively greater induction-producing power of residuals is due to the fact that the residual components associated with the several conductors are all "in phase" and their inductive effects therefore cumulative, whereas the several balanced components are "out of phase" (by 120 degrees in a three-phase system) and hence their resultant induction is a differential effect, *i.e.*, the inductive effects due to the balanced components partially neutralize one another.

5. *Causes and Remedies for Residuals.*

Unbalances or inequalities among the admittances to ground of the several conductors of a power circuit cause residuals of the frequencies present in the voltages between conductors.* In a system without metallic connection to earth a residual voltage is produced. With a grounded-neutral system a residual current is produced and the residual voltage due to unbalanced line admittances is greatly reduced. Unbalanced admittances are caused by: (1) differences of position of the conductors with respect to ground and to one another, being a function of the configuration, height above ground, location of ground-wires and other neighboring objects, and to a small extent, of size of conductors; and (2) differences in insulation resistance, as may be due to defective insulators. Transposing the conductors, which tends to equalize their relations to ground and to one another, is an effective remedy for unbalanced capacitance. Such transpositions must be located with proper regard to changes in configuration, and at short enough distances from each other so that there is no material difference in the electrical conditions at two such points at any given instant. Of commonly occurring configurations the equilateral triangular is most nearly balanced, hence causes the least residuals due to unbalanced capacitances, while the plane configurations, especially the unsymmetrical horizontal, are the worst in this respect. The remedy for

*It is to be noted that the unbalances here referred to are not unbalances such as those due to single-phase loads between line conductors.

unbalanced insulation resistance lies in careful maintenance; for a well constructed and maintained system this is usually not an important source of residuals.

In a power system having loads connected between the several conductors and ground (as in a star-connected system with grounded neutrals), differences among the loads of the several phases may cause residual voltages and currents, due to part of the load being supplied through a circuit consisting of conductors with ground "return." Inequalities of ratios or impedances among the transformers of a bank also cause residuals in such a circuit. The evident remedy is careful equalization of loads, and the use of like transformers. Removal of the ground path for unbalanced load currents, allowing only one neutral ground, is the most effective and reliable remedy for this source of residual current.

When a transformer bank in a three-phase system is connected in star with neutral grounded, harmonics of three times the fundamental frequency, and odd multiples thereof, appear as residuals, on the grounded-neutral side. This is because of the variation of the permeability of the transformer iron with varying magnetic density, causing harmonics in transformer exciting currents or in their induced voltages. As the triple-harmonic components are "in phase" in the three transformers, triple-harmonic residual voltages and currents are produced if the neutral is grounded. Delta-connected windings on such a transformer bank provide a shunt path for these triple-harmonic components of the exciting current, and greatly lessen the residuals which might otherwise be caused on the grounded neutral side. Since the magnitude of these residuals decreases very rapidly as the maximum magnetic density is reduced, lowering the voltage impressed per turn of the transformer winding, or substituting transformers of lower magnetic density, is a very effective remedy. Isolating the neutral of a transformer bank eliminates it as a source of triple-harmonic residuals.

Generators with star-connected armature windings may cause residuals due to: (1) inequalities among the voltages induced in the several windings; (2) departure from ideal phase differences, 120 degrees for a three-phase generator; (3) triple-harmonic voltages of the three windings being in phase, between neutral and line terminals. When a generator is connected to the line either directly or through auto-transformers, residuals are thus caused only if the generator neutral is grounded. When connected to the line through transformers residuals will result from these causes if the transformer bank is star-star connected with line-side neutral grounded and station-side neutral connected to generator neutral. The remedies are: (1) careful design and construction, (2) avoidance of grounded neutral or transformer connections permitting transformation of generator residuals to line (as by the use of a delta connection on the generator side of the transformers).

The grounding of transformers, transformer banks or generators at unsymmetrical points of their windings unbalances the electrically connected circuit and thereby causes a residual voltage and current. The remedy is obvious.

6. *Factors Affecting Intensity and Magnitude of Induction.*

(*a*) *Dimensional Factors.* In general, as the horizontal separation of power and communication lines is increased, the induction decreases at a rate varying, roughly, from direct proportionality to about the third power of the separation. That is, doubling the separation reduces the induction from unity to some value between one-eighth or less and one-half. The rate of decrease is less for magnetic induction than for electric induction and less for induction in grounded circuits than for induction in metallic circuits. When the disturbed and disturbing circuits are very close together, the rate of decrease may be less than stated above and in some instances, notably with the vertical-configuration power circuit, there may be an increase of induction at first, as the separation increases.

Other things being equal, the magnitude of the induction increases nearly in direct proportion to the length of parallel.

The configuration of a power circuit has a large influence on the intensity of the induction from balanced voltages and currents, but a very small influence on induction from residuals. No one configuration commonly employed can be selected as universally superior, since the one giving the least inductive effect depends on the spacing of the conductors and the relative position of the two classes of circuits, also upon the type of induction, electric or magnetic, which preponderates.

Induction from balanced components increases nearly in direct proportion to the spacing of power conductors, but induction from residuals, particularly residual current, is only slightly affected by the conductor spacing.

The intensity of the direct induction in metallic communication circuits depends largely upon the arrangement of the conductors and increases in direct proportion to their spacing (for two-conductor circuits in a given plane) ; but the inductive effects on the conductors as a group, with reference to the earth as a neutral conductor, are only slightly affected by the spacing or arrangement.

(*b*) *Electrical Factors.* The induced current in a communication circuit increases in direct proportion to the magnitude of the voltage or current in the power circuit which causes it, and approximately in proportion to the frequency of the inducing voltage or current.

As stated above, residual voltages or currents produce much more intense inductive effects than balanced voltages or currents of the same magnitude.

The magnitude of the induced current is considerably affected by the amount and character of line and of terminal apparatus between the parallel or source of disturbance and the receiving instrument. The primary effect of such sections of unexposed line and apparatus is to diminish the received current.

Several communication conductors on one line tend to shield one another. It is generally assumed that ground-wires, as commonly employed for lightning protection on power lines, are shielding agents. This is true with respect to inductive effects from residual voltages and currents, but such ground-wires may increase the intensity of the induction from balanced voltages and currents, by distortion of the electric and magnetic fields about the power circuit.

Using the well-known laws of electricity and magnetism, it is possible to determine by computations the effect of these various factors, both dimensional and electrical, in simple practical cases. Even with the simplifying assumptions allowable, the work is usually tedious. In complex cases as when the simultaneous action of all factors is to be considered, quantitative results are best obtained by experimental means.

7. *Transpositions.*

One of the most valuable means of overcoming inductive interference under normal operating conditions of power circuits is to transpose the conductors of each circuit, so as to equalize their relations to all other circuits and to earth.

Transpositions in a power circuit tend: (1) to equalize the capacitances of its conductors to ground, thereby removing a source of residuals, and (2) to cause the inductive effects from the balanced voltages and currents to neutralize one another in neighboring lengths of a parallel communication line. Transposition of a power circuit does not reduce induction from residuals, except as it may do so indirectly by a reduction in the magnitude of the residuals as just noted.

Transpositions in a communication circuit tend: (1) to equalize the capacitances of its conductors to ground; (2) to lessen the induction among the several communication circuits of a line (known as ''cross-talk'' on telephone circuits); and (3) to equalize the inductive effects on the two sides of the circuits, due to near-by power circuits. Such transpositions do not protect the circuit against voltages induced between the circuit as a whole and ground or along the conductors as a group.

In order that transpositions shall be most effective they must be carefully located, within sections where the intensity of the inductive effects is uniform, with respect to points where the induction changes, called points of discontinuity. The transpositions in each class of line must also be located with regard to the transpositions of the other class of line, *i.e.,* the transpositions in the power and communication lines must be co-ordinated.

On account of the finite (though very short) time required for electric waves to travel along the conductors, the electrical conditions at a given instant will be different at different points along the lines, being practically opposite at points one-half wave length apart; hence transpositions laid out on a basis of uniform conditions do not produce perfectly neutralizing and equalizing effects in adjacent sections of a parallel. To be effective, therefore, the nominally balanced lengths of a transposition scheme should be very short as compared to a wave length at the frequencies of induction to be considered and guarded against. The impairment of balance due to this effect varies approximately as the square of the length of nominally balanced section and directly as the frequency of the induction. It is usually advantageous to omit transpositions at the junction points of successive balanced sections, or barrels of the power circuit, as this lessens the impairment of balance just mentioned.

The length of parallel within which a nominal balance should be obtained in a scheme of transpositions designed to adequately reduce

interference, is usually determined by the points of discontinuity, the lengths of sections thus required adequately meeting the requirement above mentioned of securing balance within a small fraction of a wave length. In long uniform parallels involving telephone circuits, balanced sections with barrels in the power circuits three miles in length are usually adequate. For such parallels involving telegraph circuits longer barrels are permissible as only the wave length of fundamental frequency need be considered.

Though transpositions afford a very practical and effective means of mitigation for some inductive disturbances, they cannot be considered as a complete remedy for interference even under normal operating conditions.

8. *Unbalance of Communication Circuits.*

Differences in the admittances to ground or series impedances of the two conductors of a metallic communication circuit cause currents in its terminal apparatus when a voltage is induced between its conductors and ground or along its conductors in multiple. These unbalances may be reduced to the smallest practicable values by transposing the conductors and by proper design, construction and maintenance of open-wire lines, cables and connected apparatus. A small amount of unbalance is, of course, unavoidable. Since the induced currents here considered are proportional to the product of the unbalance and the induced voltage, it is necessary to restrict the amounts of either or both these factors in order to sufficiently limit the induced currents in the terminal apparatus of metallic telephone circuits.

9. *Transients and Abnormal Conditions.*

When a section of power circuit is energized or de-energized a sudden change takes place in the electric and magnetic fields about the circuit. If the several conductors are not energized or de-energized at exactly the same instant, large residual voltages and currents exist momentarily. An extreme case of this sort occurs when single-pole switches are operated successively, or when one pole of a switch fails to operate.

When one conductor becomes grounded there is a sudden change from a condition of approximate balance to one of large unbalance which persists until the circuit is de-energized or the fault cleared.

At the time of such abnormal conditions of power circuits the induction in parallel communication circuits is greatly in excess of that experienced under conditions of normal operation, sometimes causing hazardous voltages, and acoustic shocks to telephone users. If the protective devices of communication circuits are operated, service interruption continues for a considerable period after the initial cause has subsided, until such devices are restored. Where telephone circuits are affected the operating personnel may be temporarily demoralized by severe acoustic shocks. An ''arcing ground'' on a power circuit not normally connected to ground may continue for some time with constant repetition of the accompanying transients, and corresponding severe disturbance.

The means sometimes employed in handling faults in power circuits of repeatedly re-energizing the faulty circuit, either to burn off a "ground" or locate it by sectionalization, often greatly aggravates the disturbance to communication circuits by repetition.

Abnormal conditions and severe switching transients are, aside from their detrimental effects on communication circuits, very undesirable from the standpoint of power-system operation. The frequency of their occurrence can only be lessened by high-grade design and construction and by careful operation and maintenance.

10. *Nonessential Features Cause Greatest Interference.*

It will be apparent from the foregoing that those features of power and communication circuits, which have the greatest tendency to result in interference, while not wholly avoidable, are nonessentials which serve no useful end in the normal functioning of the circuits, and that the necessary precautions for the prevention of inductive interference are not incompatible with a high grade of service but to some extent further that end. This circumstance is fortunate alike for the public, the power companies and the communication companies.

GUIDING PRINCIPLES FOR PREVENTING INTERFERENCE.

The following are the basic physical principles which underlie the rules recommended in Part Three and which should guide all efforts to prevent inductive interference.

1. Avoidance of close proximity.

By no other means can complete freedom from interference be secured.

2. Elimination or suppression of harmonics.

To the existence of harmonics is due practically all interference to telephone circuits under the normal operating conditions of parallel power circuits. Improvement in this respect may be effected by giving due regard to its importance in the purchase of new equipment.

3. Limitation of residuals.

The intensity of the induction due to residual voltages and currents is relatively more severe than that due to balanced voltages and currents and induction arising from residuals cannot be neutralized by power transpositions. They can be lessened by balancing the line and also the load, by the use of advantageous transformer connections and by the avoidance of excessive magnetic density in the iron cores of transformers.

4. Reduction of intensity of induction by favorable arrangements of conductors.

Within the latitude afforded by various practical configurations of power and communication circuits the induction with some arrangements is of much less intensity than with others. In cases of multi-circuit power lines important advantage can be secured by care in fixing the phase relations of the conductors of the several circuits.

5. Neutralization of induction by co-ordinated transposition systems.

By means of transpositions in both classes of circuits within a parallel the phase or direction of the induction may be controlled so that mutually neutralizing effects are created in neighboring lengths of circuit. To be effective the transposition systems of the two classes of lines must be *co-ordinated.*

6. Balancing of metallic communication circuits.

Accurate balancing of metallic communication circuits, particularly telephone circuits, tends to reduce the disturbing effect of induction from parallel power circuits and other near-by communication circuits. Unbalances are reduced by transposing the conductors and by careful design, construction and maintenance of lines and apparatus.

7. High-grade construction and care in the operation and maintenance of power circuits.

No means are known, except increased separation of the two classes of lines, whereby the severe momentary disturbances to communication circuits, due to abnormal conditions on neighboring power circuits, can be prevented; hence the importance of minimizing such occurrences by high standards of construction, operation and maintenance.

PART THREE.

REVISED RULES RECOMMENDED BY COMMITTEE.

Reasons for Revising Rules.

Since submitting its preliminary report, dated July 7, 1914, recommending provisional rules for the prevention or mitigation of inductive interference which were later embodied in General Order No. 39, this Committee has greatly extended its investigations of some important branches of the subject. Considerable experience in the practical application of the rules has also been gained. In the light of the additional information thus made available and with due consideration of criticisms and suggestions which have been offered by others, the Committee has formulated, and herewith presents, revised rules which it recommends be embodied in a new order of the Railroad Commission to supersede General Order No. 39.

In formulating these revised rules, the Committee has endeavored to utilize the information obtained since its former report so that the rules may be, so far as practicable, definite and authoritative in respect to the specific limitations. The general arrangement of the rules has been modified in order to better meet the requirements of practical use. A detailed discussion of such of the provisions as seem to require it is given in a section immediately following the rules.

Text of revised rules.

RULES GOVERNING THE CONSTRUCTION AND OPERATION OF POWER AND COMMUNICATION LINES FOR THE PREVENTION OR MITIGATION OF INDUCTIVE INTERFERENCE.

I. GENERAL PROVISIONS.

(a) Applicability of rules.

These rules, except as otherwise provided in I (*e*) shall apply and be effective as follows:

1. Rules limited to lines involved in a parallel,* or to apparatus connected to such lines, shall apply only in case of parallels created hereafter; except that rules relating to operation or maintenance shall apply to all such lines and apparatus, both existing and new.

2. Rules not limited to lines involved in a parallel, or to apparatus connected to such lines, shall apply to new construction only, including, however, existing lines and apparatus when such are generally reconstructed or renewed.

(b) Co-operation.

Any party contemplating new construction which may create a parallel shall confer with the other party or parties concerned and they shall co-operate with a view of avoiding the parallel, or, if this be impracticable, of minimizing the resulting interference. Failure to comply with this requirement will receive consideration by this Commission in any subsequent issue involving such construction.

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*For definition of "parallel" see page 32.

(c) Principle of least cost.

When there are two or more different practicable methods of avoiding or mitigating interference, the method which involves the least total cost shall in general be adopted irrespective of whether the necessary changes are made in the plant of the party creating the parallel or in the plant of the other party; provided, however, that preference shall be given to methods of avoiding a parallel over methods of mitigating interference; and provided, further, that as between different methods of mitigation having different degrees of effectiveness, the most effective method, the cost of which can be justified, shall be adopted. In estimating such costs, all factors of expense to both parties shall be taken into account.

(d) Existing parallels.

Parties operating power or communication lines shall exercise due diligence in applying measures, in general accordance with the principles of these rules, for mitigating inductive interference due to existing parallels. Any such parallels which now or hereafter cause excessive interference shall be attended to promptly.

When lines involved in existing parallels are added to, extended or generally reconstructed, or when additional apparatus is connected to such lines, or when apparatus now connected to such lines is renewed or rearranged, the new or changed plant shall thereafter conform to the provisions of these rules.

(e) Saving clause.

The Commission reserves the right to modify any of the provisions of these rules in specific cases, when in the Commission's opinion, public interest would be served by so doing.

II. DEFINITIONS.

Certain technical terms are employed herein in the senses set forth in the following definitions:

(a) Class H power circuit.

The term "Class H Power Circuit" means any overhead open-wire constant-potential alternating-current power transmission or distribution circuit or electrically connected network which has 5,000 volts or more between any two conductors or 2,900 volts or more between any conductor and ground; except railway trolley circuits and feeders electrically connected therewith.

(b) Electrically connected.

The term "Electrically Connected" means connected by a conducting path or through a condenser, as distinguished from connection merely through magnetic induction.

(c) Signal circuit.

The term "Signal Circuit" means any telephone, telegraph, messenger call, clock, fire, police alarm, or other circuit of similar nature used exclusively for the transmission of signals or intelligence, which

operates at less than 400 volts to ground, or 750 volts between any two points of the circuit, provided that if the voltage exceeds 150, the power transmitted shall not exceed 150 watts.

(d) Communication circuit.

The term "Communication Circuit" means any overhead open-wire signal circuit, except that, if such circuit be a telephone circuit, it is limited to inter-exchange metallic telephone circuits and to metallic telephone circuits operated by a railroad or other company for dispatching purposes, or for public use between separate communities.

(e) Line.

The term "Line" means any circuit or aggregation of circuits carried on poles or towers, and includes the supporting elements.

(f) Parallel.

The term "Parallel" means a condition where a Class H Power circuit and a communication circuit follow substantially the same course or are otherwise in proximity for a sufficient distance so that the power circuit is liable to create inductive interference in the communication circuit.

With some parallels interference occurs only at times of abnormal conditions on the power circuit in which case such of these rules as affect induction only under normal operating conditions do not apply. When the application of any rule is thus restricted, the condition under which the rule applies is referred to as a "normal" parallel.

(g) Configuration.

The term "Configuration" means the geometrical arrangement of a circuit or circuits, including the size of the wires, and their relative positions with respect to one another and earth.

(h) Transposition.

The term "Transposition" denotes an interchange of position of the conductors of a circuit between successive lengths thereof.

(i) Barrel.

The term "Barrel" means an arrangement of a section of power circuit of uniform configuration within which each conductor occupies each of the conductor positions for equal distances.

(j) Discontinuity.

The term "Discontinuity" means any abrupt change in the relative positions of a power and a communication circuit, or any abrupt change in configuration, line impedance or load along either such circuit (including such changes due to connected circuits, transformers, cables, loading coils or other apparatus) which materially affects the magnitude or phase of the induced voltages or currents per unit length or the capacitances of either circuit. Transpositions, however, are not considered to be discontinuities.

(k) Co-ordination.

The term "Co-ordination" as applied to transposition systems means that the transpositions in power and communication circuits involved in a parallel are efficiently located, with respect to each other and to the discontinuities, for reducing the inductive effects on the communication circuits.

(l) Balanced and residual voltages.

The voltages *to ground* of the several wires of a power circuit are divided for convenience into two classes of components, "balanced" and "residual."

The "balanced voltages" are those components which are equal in magnitude and have such phase relations that their algebraic sum is zero at every instant.

The remaining components of the voltages to ground, which exist under conditions other than perfect balance, are termed residual. They are equivalent to a single-phase voltage impressed between the power wires in multiple and ground. The sum of the residual components is termed the "residual voltage" of the circuit. In case of a three-phase circuit it is three times the equivalent single-phase voltage above mentioned.

Mathematically expressed, the residual voltage is the vector sum of the voltages to ground of the several wires of a power circuit, while the balanced voltages are those components whose vector sum is zero.

(m) Balanced and residual currents.

The currents in the several wires of a power circuit are divided for convenience into two class of components, "balanced" and "residual."

The "balanced currents" are those wholly confined to the wires of the circuit. Hence their algebraic sum is zero at every instant.

The remaining components of the currents in the several wires, which exist under conditions other than perfect balance, are termed residual. The sum of the residual components is the "residual current" of the circuit. It is equivalent to a single-phase current in a circuit having the power wires in multiple as one side, and ground as the other side.

Mathematically expressed, the residual current is the vector sum of the currents in the several power wires while the balanced currents are those components whose vector sum is zero.

III. LOCATION OF LINES.

(a) Avoidance of parallels.

Every reasonable effort shall be made to avoid creating parallels. If the parties concerned can agree upon a plan for providing an adequate separation of the two classes of lines so as to avoid interference, such plan shall be put into effect. In no case shall a parallel be created unless the cost of avoidance by separation is greater than the cost of the remedial measures required by these rules.

(b) Notice of intention.

The party proposing to build a new Class H power or a communication line which will create a parallel, or generally to reconstruct or

change the operating conditions of an existing line involved in a parallel, shall give due notice (at least sixty days where practicable but in any event not less than twenty days in advance of construction, except for minor extensions, for which notice shall be given immediately after the work is authorized) of such intention to the other party including full information as to the location within the parallel and such other features of the proposed line as would affect induction.

(c) Distance between lines.

Class II power lines and communication lines shall be kept as far apart as practicable. Their separation should be at least equal to the height above ground of the power wires, except when closer proximity is unavoidable.

If, in any case of inductive interference, it should be found impracticable to obtain a proper degree of relief by means of the remedial measures set forth in these rules or by other measures of a remedial nature, the parties concerned shall agree upon and put into effect a plan for increasing the separation of the lines within the parallel.

To promote the effective application of transpositions, both parties shall endeavor to maintain a uniform separation of the two lines throughout each normal parallel. However, in general, when it is feasible to secure more than a 20 per cent increase in separation, for a distance in excess of one mile, this shall be done.

(d) Length of parallels.

Parallels shall be made as short as practicable.

(e) Discontinuities.

In the location, construction and general reconstruction of lines within normal parallels every reasonable effort shall be made to avoid discontinuities (except those due to increases in separation as provided for in (*c*) above) which would interfere with the application of effective and economical co-ordinated transposition systems in the power and communication lines.

In the location and construction of the first line along a public highway, special effort shall be made to avoid crossing the highway and also to avoid other features which would result in unnecessary discontinuities in the event of the construction of another line along the same highway.

IV. DESIGN AND CONSTRUCTION OF LINES.

(a) General requirements.

The quality of material, workmanship, methods and grade of construction shall be in accordance with approved modern practice with special regard to the prevention of failures and the avoidance of features, such, for example, as inferior insulation, which would tend to cause or promote inductive interference.

(b) Arrangement and spacing of power conductors.

In the design for construction or general reconstruction of Class II power lines, consideration shall be given to the configuration of the lines

with a view to minimizing (1) throughout the entire length of the line inequalities among the capacitances to earth of the conductors; and (2) within normal parallels the intensity of the inductive effects. When two or more circuits are carried on one line the phase relations among the conductors of the different circuits should be chosen with the same purposes in view. The configurations to be preferred for three-phase lines under different conditions are discussed in the Exhibit attached hereto.

Excessive spacing of conductors should be avoided.

Two-wire branches electrically connected to a three-phase Class II power circuit should be avoided except those so short that they do not materially unbalance the three-phase circuit. Where such branches are employed they should be so distributed as to cause minimum unbalance.

No single-wire grounded Class II power circuits or branches of multiwire Class II power circuits shall be employed.

(c) Transpositions—General.

All Class II power circuits and metallic communication circuits, or extensions of such circuits, hereafter constructed or generally reconstructed, shall be transposed throughout their entire lengths in such manner as to balance, as nearly as practicable, the capacitances to earth of their conductors. For single-circuit three-phase lines the maximum length of barrel for this purpose shall be twelve miles for circuits of triangular* configuration and six miles for other configurations. For twin-circuit three-phase lines the maximum length of barrel shall be six miles; except that for circuits of the vertical type (including cases with the middle conductors displaced slightly outward) and the equilateral triangular type with vertices upward, nine-mile barrels may be used when the circuits are interconnected for minimum unbalances. The accompanying Exhibit contains information concerning the methods of interconnection giving minimum unbalances.

Exceptions. Power lines, located principally on private rights of way and not electrically connected to other lines, are exempt from this rule if separated from existing communication lines, and from highways required for the future construction of communication lines, by distances not less than those given below, except for crossings at angles over 30 degrees and other sections of unavoidable closer proximity not exceeding one mile in total length in each ten consecutive miles of line, provided, however, that such sections of closer proximity to any one such communication line or highway shall not exceed one mile in each thirty consecutive miles of line.

Voltage between power conductors	Minimum separation from highways and communication lines
Below 50,000	600 feet
50,000– 75,000	750 feet
75,000–100,000	850 feet
100,000–150,000	1,000 feet
150,000–200,000	1,200 feet

For power lines meeting all these conditions for exemption except that they are electrically connected to other lines through autotransformers, the maximum lengths of barrel may be twice those specified above.

*A triangular configuration as here used means one in which the altitude of the triangle exceeds one-half the length of the longest side as base.

The question of whether highways that may be involved will be required for future communication lines shall be settled by agreement between the power company contemplating construction and the communication companies operating within the territory to be traversed. In the event of disagreement or if there is no such communication company, the matter shall be referred to this Commission. In cases where the proposed use of a particular highway by a communication company would be the determining factor in deciding whether a given power line must be transposed, such communication company shall make an effort to locate its proposed line elsewhere and the decision shall be made in accordance with the principle of least cost laid down in I (*c*).

Existing Class II power circuits and those exempted under the preceding paragraph, which hereafter become involved in normal parallels, shall be transposed so as to balance their capacitances to earth, when necessary for limiting residual voltages and currents to amounts which can be tolerated. The location and number of transpositions for this purpose shall be determined by agreement of the parties concerned.

In the location and spacing of the transpositions due regard shall be paid to discontinuities which affect the capacitances of the circuit. Sections of circuit between such points of discontinuity should be treated independently.

In general, transpositions should be omitted at the junction points of successive barrels.

Metallic communication circuits, and single-phase and two-phase Class II power circuits, shall be transposed at intervals not exceeding four miles.

Power circuits less than three miles in length are not required to be transposed outside of parallels, except when the absence of transpositions would materially impair the balance of other circuits to which they are electrically connected.

Power circuits with grounded neutrals, having a voltage of less than 12,500 volts, between conductors, are not required to be transposed outside of parallels, except where the lack of such transpositions in any specific case is the cause of interference.

Within normal parallels the transpositions in the two classes of circuits shall be as provided in (*d*) below. When the transpositions required in a parallel impair the general transposition system of either line outside the limits of the parallel, the necessary readjustment of transpositions shall be made in the sections of line adjacent to the parallel, as a part of the remedial measures therefor.

(d) Transpositions—Inside limits of parallels.

Within each normal parallel an adequate scheme of transpositions, to neutralize, so far as practicable, the inductive effects, shall be installed in the power circuits, and also in the communication circuits, provided the latter are metallic. The transposition systems in the two classes of circuits shall be properly co-ordinated. The parties concerned shall co-operate to determine upon the transposition scheme to be employed. The transpositions required in the line last constructed shall be installed before it is placed in service.

In applying the foregoing, the following rules shall, in general, be observed:

1. For each normal parallel at least one barrel shall be installed in the power circuit. This applies also to a section of parallel where it is not practicable to obtain a balance by combining it with another section. In applying this rule it is not intended ordinarily to change the span lengths required for other purposes.

2. In long uniform parallels or sections of parallel, involving a telephone line at highway separation from the power line, the barrels shall be three miles in length, subject to such variation as may be necessary for co-ordination with the transpositions required in the telephone circuits. Transpositions should in general be omitted at the junction points of successive barrels.

3. Except as modified by (1) above, the number of transpositions required in power circuits paralleling telephone circuits shall be subject to the following limitations expressed in terms of the average distance between successive transpositions:

> For power circuits of 50,000 volts or more between conductors, not less than one mile.
>
> For power circuits of less than 50,000 volts between conductors, not less than one-sixth mile.*

4. In case of a parallel between a power line and a telegraph line or other grounded communication line, the transpositions in the power circuit shall be located with due regard to the limits of the parallels and to discontinuities, in order to form as nearly as practicable a balanced system, subject to the condition that the transpositions in the power circuit are not required to be less than one mile apart, except as modified by (1) above. In long uniform sections of parallel, barrels six miles in length should be sufficient. Transpositions should be omitted at the junction points of successive barrels.

5. The question of the most economical scheme to accomplish the purpose shall always be considered. Effort shall be made to utilize as many as practicable of the existing transpositions.

It is suggested that in case of a short section of new line, not sufficient of itself to require transpositions, but which is likely to be extended later so that transpositions would then be necessary, consideration be given to the advisability of installing one or more suitably located transpositions in the new section of line while it is being constructed in order to avoid interrupting the service by adding transpositions afterwards.

Exceptions. Cases of parallelism may occur where the interference is due almost wholly to residual voltages and currents in which event transpositions in the power circuit are not required, except as provided in IV (*c*).

V. DESIGN, CONSTRUCTION AND ARRANGEMENT OF APPARATUS.

(a) Quality and suitability.

In designing, specifying, or otherwise determining the quality or suitability of apparatus to be connected to Class II power or communication

*While barrels of approximately three miles, as provided in 2 above, are generally to be employed, the shorter barrels specified in 3 are sometimes necessary in short parallels and in short sections of parallels, in order to co-ordinate with the discontinuities and obtain a proper degree of balance.

circuits, and in arranging such apparatus for use, effort shall be made to avoid, so far as is reasonably practicable, all features which would tend to create or promote inductive interference under either normal or abnormal conditions. As instances in applying the foregoing, the following rules shall be observed.

(b) Rotating machinery.

In order to improve conditions generally, companies operating Class II power circuits shall make every effort to minimize the high frequency components of voltages and currents caused by rotating machinery. All new rotating machinery shall have as nearly as practicable a pure sine wave of voltage and shall not, in any case, deviate therefrom to exceed the limit set forth in the present standardization rules of the American Institute of Electrical Engineers.

No ground connection shall be used on the armature winding of an alternating-current generator or motor electrically connected to a power circuit involved in a normal parallel unless means are employed to avoid unbalancing the circuit and to reduce triple-harmonic residuals as far as may be necessary and practicable.

(c) Transformers and their connections.

In order that the wave-shape of voltage and current may be distorted as little as practicable by transformers, all new transformers on Class II power circuits should have an exciting current as low as is consistent with good practice, and which shall not, at rated voltage, exceed 10 per cent of the full load current; except that for transformers without neutral ground connections on the line side, the exciting current at rated voltage need not be less than 0.2 ampere.

Where three-phase transformers are employed with grounded neutrals the core type is preferable to the shell type.

Transformers or transformer banks shall not be grounded at such points of their windings as to unbalance a connected circuit involved in a normal parallel. As important cases under this rule, no grounded single-phase, grounded three-wire two-phase, or grounded open-star three-phase connection shall be so employed.

No star-connected transformers or autotransformers shall be employed with a grounded neutral on the side connected to a three-phase power circuit involved in a normal parallel, unless low-impedance delta-connected secondary or tertiary windings or other equivalent means are used for suppressing the triple harmonic components of the residual voltages and currents introduced by the transformers.

Care shall be taken that the individual units in each grounded-neutral bank of transformers, connected to a circuit involved in a normal parallel, are alike as to type and rating, including all electrical characteristics, and that they are similarly connected, so as not to unbalance the circuit.

Closed-delta connections shall be used wherever practicable in preference to open-delta connections on three-phase power circuits involved in normal parallels. When open-delta connections are employed, an effort shall be made to distribute such connections equally among the three phases.

Where triple harmonic residual voltages and currents due to star-connected transformer banks exist in amounts which can not be tolerated, and it is inexpedient to isolate the transformer neutrals, such residuals shall be limited by operating the transformers at reduced magnetic density or by other available means.

(d) Rectifiers.

Rectifiers and other apparatus tending to distort the alternating current wave when installed on power lines involved in normal parallels, shall, if necessary, be equipped with suitable auxiliary apparatus to prevent harmful distortion of the wave-form of power-circuit voltage or current.

(e) Switches.

Each oil-break switch in a power-circuit involved in a parallel, located between the source or sources of energy and the parallel, and used for energizing or de-energizing the circuit, shall have all poles mechanically interconnected for simultaneous action. There shall be at least one such switch so located as to control the supply of energy to each power circuit involved in a parallel, and, except at stations where an operator is constantly on duty, such switch shall be made automatic for short circuits, grounds, and in case of grounded neutral circuits, for abnormal neutral grounds.

Careful consideration shall be given to means of minimizing transient disturbances caused by switching operations on Class H power circuits, which would cause inductive interference. Wherever practicable provision shall be made for switching on the station-side rather than on the line-side of transformer banks.

Oil-break switches, having their poles mechanically interconnected for simultaneous action, shall be provided wherever the use of air switches or noninterconnected single-pole oil switches would cause harmful transient disturbances in parallel communication circuits.

(f) Fuses.

Switches shall be used instead of main line fuses wherever practicable in a power circuit involved in a parallel.

(g) Electrolytic lightning arresters.

When electrolytic lightning arresters are employed on a power circuit involved in a parallel they shall be equipped with auxiliary charging resistances and contacts so arranged that the horn gaps are short-circuited at the time of charging, to avoid, as far as possible, the production of arcs.

(h) Special instruments.

Reliable indicating devices shall be installed at the source of supply of power circuits involved in parallels, to inform the operators immediately of abnormal conditions, such as grounds, and wherever possible, open circuits, which have not operated automatic switches.

Whenever a neutral ground connection is employed on a circuit involved in a parallel, an ammeter, suitable for measuring the current in the neutral under normal operating conditions, shall be installed in

each neutral connection to ground at the main generating and main attended substations on the power system electrically connected to the circuit involved in the parallel.

(i) Communication apparatus.

All apparatus electrically connected to metallic communication circuits involved in parallels shall be designed and constructed so as to secure as nearly as practicable an accurate balance of the series impedances and the admittances to earth of the two sides of the circuits in order to minimize the detrimental effects of induction from parallel power circuits.

VI. OPERATION AND MAINTENANCE.

(a) General requirements.

Power and communication companies shall use all reasonable means to operate and maintain circuits involved in parallels in such a manner as to minimize interference under conditions of normal operation, and to avoid transient disturbances.

(b) Balance.

In the maintenance of both power and communication circuits involved in parallels special care shall be given to the prevention of mechanical and electrical failures which would cause or promote transient disturbances or unbalances such as those due to tree-grounds, defective or dirty insulators or other faults.

The voltages and currents of power circuits involved in parallels shall be kept balanced as closely as practicable and accidental unbalances shall be promptly corrected.

(c) Record of neutral current.

At all points on grounded neutral systems equipped as required in V (*h*), the power company shall observe and record daily the approximate maximum neutral current.

(d) Transformers.

No transformers connected to power circuits involved in normal parallels shall be operated at more than 10 per cent above their rated voltage. Wherever practicable in case of existing equipment and in all cases of new equipment, transformer banks with grounded neutrals on the side which is connected to a power circuit involved in a normal parallel shall not be operated at more than 5 per cent above their rated voltage.

(e) Switching.

In all switching operations care shall be taken to avoid, so far as possible, the production of harmful transient disturbances.

(f) Charging electrolytic lightning arresters.

When, notwithstanding compliance with V (*g*), interference is caused by charging electrolytic lightning arresters, such charging shall be done at night, so far as is possible, preferably between 2 a.m. and 4 a.m.

(g) Abnormal conditions.

Power companies shall adopt operating rules which shall specifically outline the procedure for their operators during times when a power circuit involved in a parallel is abnormally unbalanced, as will occur with an open, grounded or short-circuited line or transformer winding.

Such rules shall in general provide for the discontinuance of operation of the power line until the fault is remedied, excepting only those cases where it is clear that the service rendered the public by continuing operation of this section of power line is of greater importance than the communication service interrupted by such continued operation.

When it is necessary to energize a defective power line in order to locate a fault, care shall be taken to avoid, as far as possible, repeatedly energizing any section of such line which parallels communication circuits, until the fault has been cleared. Whenever possible the faulty section of line shall not be energized more than once until disconnected from the section of line involved in the parallel.

To facilitate the study and prevention of disturbances in communication circuits, occasioned by transient conditions of power circuits, accurate record shall be kept of the nature and time of occurrence of failures, changes in operating arrangements and all switching during times of abnormal conditions of Class II power circuits involved in parallels; and of all transient disturbances in communication circuits. These records shall be made available for use in tracing the causes of such transient disturbances.

EXHIBIT.

ARRANGEMENT AND SPACING OF POWER CONDUCTORS.

Supplementing IV (b) and IV (c).

The arrangement and spacing of the conductors of power circuits are of importance in determining (1) the unbalances or inequalities among the capacitances of the conductors to ground, which cause residual voltages and currents, and (2) the intensity of the inductive effects produced in communication circuits by the balanced voltages and currents of parallel power circuits. For sections of line within limits of parallels, consideration of the inductive effects should in general control rather than consideration of the capacitance unbalances. For sections of line outside the limits of parallels, consideration of capacitance unbalances should be given the greater weight, particularly for circuits operated without grounded neutrals.

The figures and comparisons given herein apply to nontransposed circuits, but the comparisons of different configurations hold also for transposed circuits, provided the circuits are transposed identically. If there were no irregularities or inexactnesses to impair the effectiveness of a transposition system, it would be possible theoretically, neglecting the effect of phase change and attenuation, to obtain a perfect balance by means of transpositions, irrespective of the arrangement of the conductors. Practically, however, circuits even when

carefully transposed have a material resultant unbalance, particularly at the frequencies of the higher harmonics, and this unbalance is proportional to the unbalance characteristic of the circuit configuration. In a similar manner the resultant induction due to a power circuit is proportional to the intensity of the induction characteristic of the configuration. Configurations differ widely in respect to their characteristic unbalances and intensities of induction, some arrangements, particularly of twin circuits, giving fully 90 per cent less unbalances or induction than others.

The effects of the arrangement and spacing of conductors on the unbalances of their capacitances to ground and on the induction produced in parallel communication circuits are discussed separately.

Effect on Capacitance Unbalance.

In general, the capacitances to ground of the conductors of a nontransposed multiconductor circuit are unequal, the magnitude of the percentage unbalances being determined by, and therefore characteristic of, the configuration of the circuit. This "characteristic unbalance" is an important factor in determining the residual voltage of a circuit isolated from ground, and in determining the residual current of a grounded neutral circuit, in so far as such current is caused by the line itself. Taking as a measure of the characteristic unbalance, the residual voltage of a short, uniform, nontransposed circuit without metallic connection to ground and energized with balanced three-phase voltages between conductors, termed the "characteristic residual voltage," the following table affords a comparison of various configurations of single-circuit power lines over the practical range of cross-sectional dimensions.

Characteristic Residual Voltage; Per Cent of Balanced Three-phase Voltage Between Conductors.

Configuration	
Equilateral triangle	0.5 to 4
Vertical	6 to 11
Horizontal—	
Symmetrical	5 to 9
Unsymmetrical	7 to 11
Isosceles triangle—	
Base horizontal	0 to 8
Base vertical	0.5 to 9
"L"	2 to 6
Inverted "L"	4 to 7

Triangular circuits have the smallest unbalances and characteristic residual voltages. Symmetrical horizontal and vertical circuits are about alike, the vertical having slightly the greater, and unsymmetrical horizontal circuits have the largest. The characteristic residual voltages of symmetrical horizontal and vertical configurations are from 2 to 8 times that of a corresponding equilateral triangular circuit, depending upon the spacing and height of the conductors. The characteristic residual voltages of unsymmetrical horizontal circuits are about 20 per cent greater than those of symmetrical horizontal circuits. They may, however, be reduced to those of the symmetrical cases

if the position of the intermediate conductor is alternated so that its average position is midway between the two outside conductors. (If the circuit is transposed this condition should be fulfilled in each section between transpositions.)

The characteristic residual voltages of equilateral triangular circuits are closely proportional to the conductor spacing, but the conductor spacing has but little effect in the cases of vertical and horizontal circuits.

With twin-circuit lines it is possible to interconnect the two circuits so that their unbalances tend to neutralize, giving smaller resultant unbalances among the capacitances of pairs of interconnected conductors than the unbalances among the conductors of individual circuits. For twin circuits of any type the maximum unbalances occur when conductors symmetrically located with respect to an intermediate vertical plane are at common potential. This arrangement should be avoided in all cases.

For circuits of the vertical type, or with top and lowest conductors in a vertical plane and middle conductors displaced outward a small distance, the minimum resultant unbalances are obtained when the top conductors of the two circuits are at common potential and the middle and lowest conductors of one circuit are at the potentials of the lowest and middle conductors respectively of the other. (See Figs. 1 and 2.) For triangular and horizontal circuits the minimum resultant unbalances are obtained when similarly placed conductors of each circuit are at common potential. (See Figs. 3, 4 and 5.) These figures are cross-sectional diagrams, the conductors at common potential being shown as interconnected.

The resultant unbalances with these arrangements are in some cases less than 10 per cent and in general less than 50 per cent of those with the worst condition described above. The arrangements indicated by Figs. 1, 2 and 3 give resultant unbalances of the order of magnitude of those of single-circuit equilaterial triangular lines of corresponding conductor spacing, while those of Figs. 4 and 5, in general, give greater unbalances. In all cases the characteristic residual voltage is taken as the measure of the unbalance.

Where ground wires are used or in cases where unsymmetrical circuits or more than two circuits are involved, special study is necessary to determine the best arrangement.

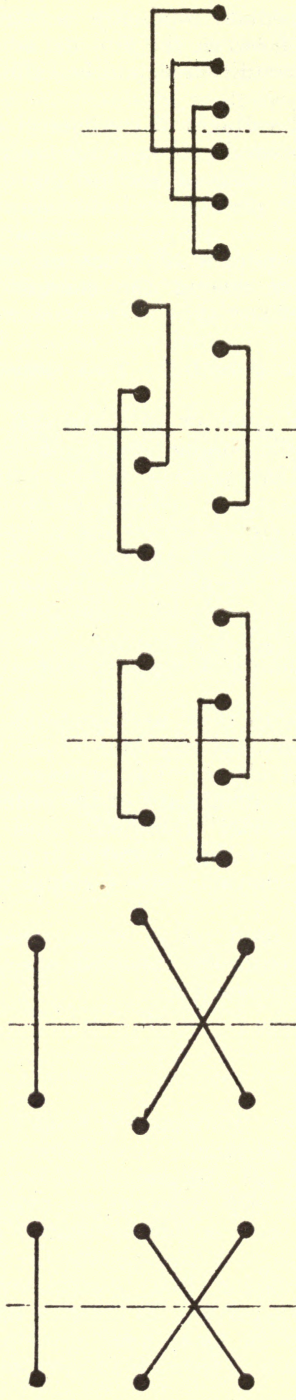

FIG. 1 FIG. 2 FIG. 3 FIG. 4 FIG. 5

METHODS OF INTERCONNECTION GIVING MINIMUM RESULTANT CAPACITANCE UNBALANCES.

With twin circuits of any configuration if the interconnection giving maximum unbalance be altered by transposing the interconnecting wires the unbalance is halved. The two possible interconnections resulting from this procedure are shown in Fig. 6. This plan is useful when there is a doubt as to the best arrangement.

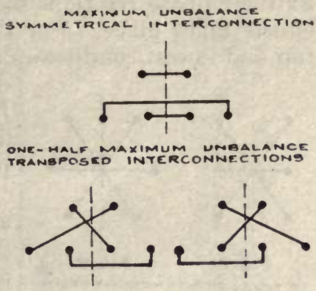

FIG. 6

To obtain the greatest advantage of arrangements giving small unbalances the twin circuits should be interconnected at both ends of the line and at intermediate substations where practicable. In cases where twin circuits are paralleled on the station side of transformer banks but can not be interconnected on the line side, it is still advantageous to fix the phase relation of the conductors as if they were to be interconnected for minimum unbalances.

When transposing twin-circuit lines to secure capacitance balance, the two circuits should be transposed at the same points and care should be taken to secure the condition for minimum unbalance in each section of line between transpositions. (See Fig. 9, below.)

The foregoing facts have an important bearing on the number of transpositions required to adequately balance different types of circuits, more frequent transpositions being necessary in circuits of large characteristic unbalances. This has been considered in IV (*c*).

Effect on Induction From Balanced Voltages and Currents.

The type of power circuit producing the least inductive effects in a parallel communication circuit depends upon the spacing of the conductors and the separation from the communication circuit. In general, for all types of circuit, an increase in the spacing of the power conductors causes a proportionate increase in the magnitude of the inductive effects. Excessive spacing should therefore be avoided. On the other hand, ample spacing to prevent short-circuits or grounds, due to snow, wind, birds, etc., is essential from the standpoint of inductive interference, as well as from that of power service.

For lines separated by the width of an ordinary highway, a vertical type of power circuit, in general, causes the smallest inductive effects, while the horizontal types cause the greatest effects, the triangular types being intermediate in this respect. The relative merits of different configurations vary somewhat with the separation of the two classes of lines and with the dimensions of the power circuit, depending also upon the relative importance of the balanced voltages and currents in producing induction.

For low-voltage horizontal lines, 15,000 volts or less, a symmetrical arrangement of the conductors is better than an unsymmetrical arrangement. For lines of any voltage, if an unsymmetrical arrangement is used, the intermediate conductor should be displaced toward the communication circuit. Hence, unsymmetrical horizontal power circuits along highways should have the intermediate conductor placed on the side of the poles *toward the road*, where communication circuits are, or may be, located on the opposite side of the road.

When two or more synchronous circuits are carried on one line it is possible to interconnect the conductors of the two circuits or otherwise fix their phase relations so that a partial neutralization of the inductive effects takes place. For twin circuits of the vertical type, or with the top and lowest conductors in a vertical plane and the middle conductors displaced outward a small distance, the most favorable condition is in general, to have the diagonally opposite conductors at common potential. (See Figs. 7 and 8.)

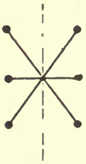

FIG. 7

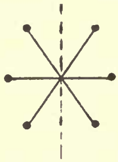

FIG. 8

METHODS OF INTERCONNECTION CAUSING MINIMUM INDUCTIVE EFFECTS

For circuits of other types the most favorable method of connection varies with the spacing and height of the power conductors and with their position relative to the communication circuit. Thus it is not possible to give a general recommendation, since special study is required in each specific case to determine the most advantageous method of interconnection. Special study is also required for lines carrying more than two circuits of the same or different voltages, for unsymmetrical double-circuit lines, and in cases where ground wires are used.

In transposing twin-circuit lines to neutralize the inductive effects in parallel communication circuits, a similar precaution should be observed, as noted above, with respect to transpositions for capacitance balance. (See Fig. 9.)

Recommended Configurations.

Taking into account both effects above discussed and practical considerations of construction, the equilateral triangular configuration (either the "horizontal-base" or "wishbone" type) is in general recommended for single-circuit power lines; and the vertical configuration (including type of construction with middle conductors displaced slightly outward from vertical plane of the other two) for twin-circuit power lines.

The method of transposing twin vertical lines to preserve the best relation of interconnected conductors both outside and inside limits of parallels is illustrated in Fig. 9, one barrel being shown in each location.

Reference.

Further information concerning the subject discussed in this exhibit will be found in Technical Reports Nos. 51, 64 and 65 of the Joint Committee on Inductive Interference. These and other technical reports are to be published by the state of California.

COMMENTS ON RULES.*

Three principal features are to be noted in comparing the revised rules with General Order No. 39:

1. The arrangement has been entirely altered in order to group related provisions of the rules and facilitate finding any particular subject.

*Not intended to be included in proposed General Order.

TRANSPOSITION OF TWIN-CIRCUIT VERTICAL POWER LINES.

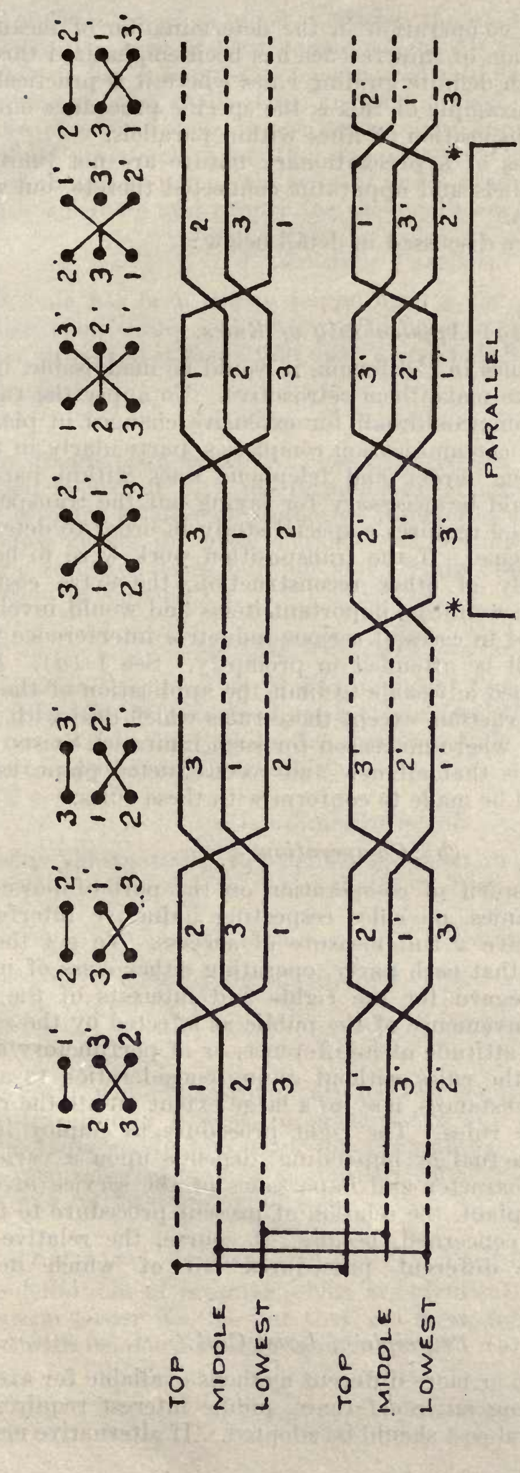

FIG. 9

* THESE TRANSPOSITIONS (IN CIRCUIT LAST INSTALLED) OCCUR ONLY AT THE ENDS OF THE PARALLEL AND ARE FOR THE PURPOSE OF CHANGING FROM THE BEST ARRANGEMENT OUTSIDE THE LIMITS OF THE PARALLEL TO THE BEST ARRANGEMENT INSIDE THE LIMITS OF THE PARALLEL AND VICE VERSA.

2. The principle of co-operation in the determination of means for avoidance and mitigation of interference has been emphasized throughout in conjunction with definite guiding rules where it is practicable to introduce them. An example of this is the specific procedure outlined in IV (*d*) for the transposition of lines within parallels.

3. Some of the rules of a precautionary nature are not limited to lines involved in parallels and apparatus connected thereto, but apply to all new construction.

Some of the rules are discussed in detail below:

I. General provisions.

(*a*) *Applicability of Rules.*

In adopting these rules in California, it would be inadvisable, in this Committee's opinion, to make them retroactive. To apply the rules to all existing construction would call for extensive changes in plant on the part of power and communication companies, particularly in transposing or retransposing power and telephone lines within parallels. Considerable time would be necessary for laying out the transposition schemes, as each parallel requires a special study in order to determine the most effective scheme. If the transposition work were to be carried out independently of other reconstruction, the extra cost and interruption to service would be important items and would involve an undue hardship, except in cases of serious inductive interference which the rules provide shall be attended to promptly. See I (*d*). It has accordingly been deemed advisable to limit the application of the rules generally to new construction, except those rules which deal with maintenance and operation where no reason for such limitation exists. The underlying principle is that all new and reconstructed plant, as it is built or installed, shall be made to conform with these rules.

(*b*) *Co-operation.*

Without a proper spirit of co-operation on the part of power and communication companies, no rules respecting inductive interference can be expected to have a full measure of success. To get the best results, it is essential that each party, operating either class of utility, recognize and have regard for the rights and interests of the other party, and also the convenience of the public as affected by the several kinds of service. An attitude of indifference, or of perfunctory adherence to the letter of the rules without giving consideration to all the various relevant circumstances, may to a large extent vitiate the results contemplated in these rules. The right procedure to employ in any case of interference, actual or impending, depends upon a variety of factors, such as the character and importance of the service involved, the effect on existing plant, the relation of present procedure to future plans of the parties concerned, besides, of course, the relative costs and effectiveness of different procedures, all of which demand co-operation.

(*c*) *Principle of Least Cost.*

Where there are two or more different methods available for avoiding or effectively mitigating an interference, public interest requires that the method of least total cost should be adopted. If alternative methods

afford different degrees of effectiveness, the method selected, if not the most effective, must at least be one which will give satisfactory results. In general, the most effective method should be chosen except where the saving in cost realized by another method is substantial and the sacrifice of effectiveness is not serious. In applying this principle to individual practical cases, the importance of the particular service affected should be taken into account and a grade of service maintained which is adequate and proper for the conditions of the case.

(d) Existing Parallels.

This rule has been drawn to conform to the principle explained in the discussion under (*a*) above. To care for cases of serious interference, provision is made that such cases shall be dealt with promptly.

II. Definitions.

(a) Class H Power Circuits.

This designates a restricted class of electrical supply circuits and is intended to accord with the terminology of other orders of this state and elsewhere relative to inductive interference and physical hazard. This class covers the great majority of circuits causing disturbances. Electric railway, series lighting and certain other circuits are treated separately in Appendix I.

(b) Electrically Connected.

"Electrical" connection is distinguished from "magnetic" connection. Electrically connected apparatus affects the balance of a circuit with respect to earth, while the corresponding effect of magnetically connected apparatus is negligible.

(c) Signal Circuits.

This is substantially the definition given in the National Electric Safety Code (Circular No. 54 of the U. S. Bureau of Standards).

(d) Communication Circuits.

A restricted class of signal circuits. Other signal circuits are considered in Appendix I.

(i) Barrel.

This term, while most commonly used in connection with three-phase three-wire circuits, applies in principle to any circuit having two or more metallic conductors, such, for example, as a four-wire circuit, in which case a barrel may be secured by three transpositions at quarter points in a uniform section of line.

(*l*) and (*m*) *Balanced and Residual Voltages and Currents.*

The definitions of residuals given are identical in meaning with those of General Order No. 39, but they are more fully explained and contrasted with balanced voltages and currents.

The division of voltages and currents of power circuits into balanced and residual components is fundamental to the consideration of effects of transpositions, power-circuit configuration, transformer connections, etc.

III. Location of lines.

(*a*) *Avoidance of Parallels.*

The first and most obvious means of preventing inductive interference is to avoid the close association of power and communication circuits. Further, it is recognized that in no other way can complete freedom from interference be secured. While, with the ever-increasing network of electrical circuits of all kinds, adequate separation to avoid interference is becoming increasingly difficult to maintain, the Committee feels that the importance of such separation justifies its being made the first premise in rules designed to prevent inductive interference.

(*b*) *Notice of Intention.*

In order to secure the time essential for determining the proper procedure in case of a parallel, advance notice is necessary. Through the opportunity for co-operative study thus afforded, means of avoidance or designs to reduce the interference can be worked out in advance and applied during the course of construction, at minimum cost and before interference develops.

(*c*) *Distance Between Lines.*

Since the inductive effects decrease rapidly with the separation of the parallel lines, the importance of this rule is evident. The effectiveness of transpositions depends upon the creation of mutually neutralizing inductive effects in neighboring sections of circuit and will in general be impaired if the intensity of induction is different in different sections of the parallel. Hence uniformity of separation is important.

(*d*) *Length of Parallel.*

Other things being equal, the inductive effects of a parallel increase in proportion to its length. Hence, parallels should be made as short as practicable.

(*e*) *Discontinuities.*

In general, the more discontinuities there are in a parallel the more transpositions are required in both power and communication circuits to provide effective balance, and since frequently it is difficult or impracticable, in the design and layout of transposition schemes, to take into account minor discontinuities which tend to nullify the effectiveness of the transpositions, all discontinuities should be avoided as far as practicable in the location and construction of lines.

Many instances have occurred where the first line along a road crossed at frequent intervals in order to cheapen construction. This procedure creates difficulties for any line subsequently constructed, besides greatly complicating the transposition scheme required to reduce inductive interference.

IV. Design and construction of lines.

(a) *General Requirements.*

As a primary consideration, power and communication lines which are liable to become involved in parallels should be designed and constructed in a proper manner, with due regard to features affecting interference, such as insulation. Severe transient disturbances to communication circuits due to abnormal conditions on power lines constitute a serious problem because there are no effective means of overcoming them. Hence, the importance of good construction in preventing the occurrence of failures on power circuits. Fortunately, construction which meets this important need will also best insure uninterrupted service of the power system itself.

(b) *Arrangement and Spacing of Power Conductors.*

The arrangement and spacing of the conductors of power circuits are of importance in determining the circuit unbalances which give rise to residuals, and in determining the intensity of the induction in parallel communication circuits due to balanced voltages and currents. By proper consideration of this matter in the design and construction of lines, the interference-producing characteristics of such lines may be materially lessened with little or no additional cost. This is particularly true of multi-circuit lines in which case great benefit may be secured simply by care in fixing the phase relations among the conductors of the different circuits. Due to lack of generally available information on this subject it is deemed advisable to give, in the form of an exhibit a brief resumé of the Committee's technical data bearing on the subject thus making possible intelligent compliance with the rule.

This rule is not mandatory with respect to any particular arrangement of conductors, for while some arrangements have important advantages over others it is inadvisable to thus restrict the type of line construction, when in many cases, by careful transposition of the line, the desired end can be attained more cheaply. Wherever practicable, however, the benefits derived by favorable arrangements of conductors should be sought as an additional safeguard against interference, particularly in case of major parallels. The great benefits obtainable by advantageous methods of interconnection of twin circuits should be secured in all such lines.

Two wire branches, metallically connected to a three-phase circuit, inherently unbalance the three-phase circuits. Even short branches of this character may cause an unbalance equal to that of the three-phase circuit without transpositions. The Committee realizes that the use of such branches offers an economical means of supplying small loads and that therefore they should not be absolutely prohibited. Every effort should, however, be made to avoid them.

Single-wire grounded power circuits are inherently completely unbalanced, that is, the entire voltage and current are residual, hence they are particularly troublesome to parallel communication circuits.

(c) *Transpositions—General.*

The unbalanced capacitances to ground of power circuits are an important cause of residual voltages and currents. This is true of grounded neutral as well as isolated circuits but is of greater importance with reference to the latter. While such unbalances may be lessened by observing certain precautions in the arrangement and spacing of the conductors as discussed above, this is not in itself sufficient and the circuit must, in general, be transposed so that each conductor occupies all of the conductor positions for equal distances, with due regard to discontinuities. In other words, an integral number of barrels, must be installed between terminals or switching points. The lengths of barrel specified are based on the unbalanced capacitances characteristic of the different configurations and upon phase-change and attenuation at the harmonic frequencies which cause the greater portion of the interference to telephone circuits.

In respect to metallic communication circuits, particularly telephone circuits, the more perfectly the capacitances of the conductors are balanced, the less the disturbing effects of induction from parallel power circuits. Unless the conductors of a circuit are symmetrically placed with respect to earth and all other conductors on the line, transpositions are necessary to equalize the capacitances to ground of the two sides of the circuit. Telephone circuits are usually transposed with respect to one another and these transpositions substantially meet the requirements of this rule.

Obviously, to undertake the transposition of the whole of an extensive power network at the time of the creation of a parallel, is very expensive, particularly in view of the interruption to service occasioned thereby. On the other hand, in the initial construction or during general reconstruction, an adequate transposition system can usually be installed at small cost as a definite part of the construction work. Such transpositions, besides serving to limit the residuals in all parallels with commercial communication circuits, are also beneficial in reducing the induction in private telephone circuits which are often on the same poles. It is recognized that some power circuits, particularly those of extra high voltage, are located on private rights of way, at such distances from highways that transpositions are not necessary for the protection of communication lines, and provision has accordingly been made for the exemption of such circuits from the general requirement of transpositions at the time of construction. In some cases, the proximity without transpositions permitted by the exception may result in serious interference, and special study should be given to cases which are on the border line.

In the matter of existing power circuits, and new power circuits coming under the above exception, which hereafter become involved in parallels, provision is made that they shall then be transposed sufficiently to limit their residual voltages and currents to amounts which can be tolerated. Since in these cases two or more parties are concerned, it is provided that the necessary transposition system shall be determined co-operatively.

(*d*) *Transpositions—Inside Limits of Parallels.*

Transposition systems in both power and communication circuits when properly co-ordinated offer the most reliable and effective means of preventing interference from the balanced voltages and currents of the power circuits.

In contrast with the corresponding rule of General Order No. 39, which allowed the communication company to specify the number and location of the transpositions in the power circuit, this revised rule provides that both parties shall co-operate to decide upon the transposition scheme to be employed. In the past most of the work of designing transposition schemes for parallels has been done by the communication companies, but so far as this Committee is aware the negotiations relating thereto have been generally conducted in a spirit of co-operation.

Three-mile barrels in three-phase power circuits co-ordinate satisfactorily with telephone transposition systems now available (designed particularly for circuits involved in parallels) and are short enough so that the effect of phase-change* along the line, in impairing the efficiency of the transposition scheme, is small. The omission of transpositions at the junction points of barrels does not usually impair the co-ordination of the transposition systems and is advantageous in reducing the effect of phase-change besides reducing the number of power transpositions. It is impossible in a rule to specify exactly the spacings of transpositions within parallels either in power or telephone lines since the spacings required vary with the circumstances being considerably influenced by the length of the parallel and by the discontinuities in both classes of line.

Barrels less than three miles in length are often very useful for securing economical and satisfactory schemes of transpositions, but in the higher voltage lines the difficulty and expense of installation are such that they are justified only in exceptional cases. For lines of lower voltages, parallels are more numerous and shorter barrels are practicable, also the greater liability of discontinuities (such as branch loads) in low-voltage lines renders necessary the greater flexibility of shorter barrels. The rules accordingly make distinction between lines above 50,000 volts and those below 50,000 volts in specifying minimum lengths of barrel. The limitations are identical with those of General Order No. 39.

Several schemes of co-ordinated transpositions can be designed for any given parallel depending upon the utilization of existing transpositions, length of barrel, type of telephone transposition system and discontinuities. Obviously, that scheme involving minimum total cost should usually be chosen. Generally in a new parallel it is economical to transpose the new line to co-ordinate in part, at least, with the existing transpositions of the prior line.

V. Design, construction and arrangement of apparatus.

(*a*) *Quality and Suitability.*

The same considerations that are mentioned under IV (*a*) which demand care in the design and construction of power and communica-

*The effect of phase-change is discussed in Technical Report No. 66.

tion lines to prevent inductive interference and to secure continuity of service, apply also to the apparatus connected to such lines.

(b) *Rotating Machinery.*

The elimination of higher harmonics from the wave form of rotating machinery strikes at the source of disturbance to telephone circuits by removing an underlying cause. It is obviously a matter which can best be cared for in specifications for new machinery.

In providing that the deviation from a pure sine wave shall not exceed the limit set forth in the present standardization rules of the American Institute of Electrical Engineers, it is recognized that this limit is unsatisfactory. This Committee has been in correspondence with a committee of the American Institute of Electrical Engineers which has under consideration the revision of the Institute's present rule on the subject. It is expected that the revised standardization rule will be more satisfactory, and it is recommended that this revised rule, when issued, be recognized by the Commission.

The improvement of wave-form in rotating machinery is essentially a problem for the manufacturer and all new machines should be designed with this in view. This Committee understands that substantial improvement in this direction can be effected at relatively small cost, hence this is one of the general precautionary rules made applicable to all new construction. For the improvement of conditions with respect to machines already manufactured and installed, the use of devices or "networks" external to the machine, designed to shunt the troublesome high-frequency components from the line, probably offers the most economical solution. The use of such devices may even prove economical with new machines.

The provision against grounding armature windings is designed to avoid a source of large harmonic residuals.

(c) *Transformers and Their Connections.*

If high magnetic densities be employed in transformers, the exciting current is large, and large higher harmonic components are introduced. The 10 per cent limit on exciting current here provided serves to guard against extreme designs but does not restrict present standard practice. It is sometimes economical to design small units for a greater exciting current. Banks of such small units, operated without neutral ground connections on the line side, do relatively little harm, hence the exception. Low exciting current is much more important for transformers of grounded neutral banks than for transformers operated without metallic connection to ground.

Core-type three-phase transformers tend to suppress their triple-harmonic exciting currents by mutual interaction in the cores. This is an important advantage over shell-type transformers, if there is a grounded neutral, as it helps to suppress triple harmonic residuals.

The grounding of transformer banks at such points of their windings as to unbalance power circuits involved in parallels is prohibited on account of the residuals thereby caused.

Star-connected transformers inherently tend to cause triple-harmonic residuals in connected transmission lines if the neutral be grounded. These residuals can be greatly reduced by providing a

shunt path for the triple-harmonic currents in the form of delta-connected windings, but such delta windings must be of relatively low impedance in order to be effective. Other means, viz, operation at low magnetic density, interconnected-star arrangements, or provision of star-delta connected transformers as shunts for the triple harmonics of star-star banks, may prove adequate in some cases.

Dissimilarities of electrical characteristics or connections among the different transformers of a grounded-neutral bank cause the power circuit to be unbalanced.

Open-delta connections cause triple-harmonic currents in transmission lines whereas in closed-delta transformer banks, such currents are locally confined.

The triple-harmonic residuals, which occur in grounded star-connected systems, practically disappear when the neutrals are isolated. However, it is not always desirable to isolate all neutrals. By reduction in operating voltage or by changes of transformer taps which reduce the magnetic density of connected transformers relatively large reduction in triple-harmonic residuals may be effected. This may in some cases prove the simplest remedy for excessive residuals.

(*e*) *Switches.*

The operation of switches is sometimes the cause of severe transient disturbances in parallel communication circuits. This is due in part to nonsimultaneous operation of the several poles of the switch which gives rise momentarily to large residuals. Oil-break switches usually complete the opening or closing of a circuit within a few cycles while air switches require a much longer time.

In order to prevent the continuance of abnormal conditions on power circuits with the consequent disturbances, lines involved in parallels should be disconnected immediately upon the occurrence of failures, and accordingly the rule provides that there shall be at least one automatic switch if prompt manual control be not available.

The transient disturbances are less severe when switching is performed on the station side of transformer banks, hence this procedure is recommended when practicable.

(*f*) *Fuses.*

The same consideration of avoiding the large residuals incident to nonsimultaneous opening of the several phases of a power circuit (referred to under "Switches"), dictates the preference for switches instead of fuses.

(*g*) *Electrolytic Lightning Arresters.*

Electrolytic lightning arresters not equipped as specified in this rule cause harmonic residuals, due to arcing, which may result in severe disturbances in parallel communication circuits. The use of charging contacts and auxiliary charging resistances largely prevents the arcing and lessens the rush of current so that such disturbances are greatly reduced.

(*h*) *Special Instruments.*

The object of this rule is to provide for immediate relief from the abnormal disturbances occasioned by grounds, open circuits, etc., which cause large residuals on power circuits, by giving notice of the existence of such unbalanced conditions.

Ammeters in the neutrals of transformer banks serve to indicate the degree of balance of the power circuit. By observing such meters, unbalances smaller than those which would operate circuit breakers can be detected. It is not necessary that such ammeters be constantly in circuit and suitable provision should be made for their protection under abnormal conditions.

(*i*) *Communication Apparatus.*

It is necessary to balance as accurately as practicable metallic communication circuits and electrically connected apparatus in order to minimize the disturbing effects of parallel power circuits. This requires that such apparatus be so designed and connected as not to introduce irregularities either in the series impedances of the two sides of the circuit or in their admittances to ground. This applies to all such apparatus, including that used for superposed grounded signalling systems (such as telegraph on telephone), although such balancing has no effect on interference with the superposed grounded system itself.

VI. Operation and maintenance.

(*b*) *Balance.*

It is to be expected that by careful inspection and maintenance incipient causes of failures can be detected and corrected before they develop serious consequences. In this way interruption to service can be avoided as well as severe disturbances to parallel communication circuits.

(*d*) *Transformers.*

This rule is designed to limit the introduction of harmonics due to excessive magnetization of transformers, which occur when they are operated at voltages above normal. Such overvoltage operation is particularly undesirable in the case of grounded-neutral banks of transformers.

(*e*) *Switching.*

Examples of compliance with this rule are, the use of oil-break switches with poles mechanically interconnected for simultaneous action instead of air-break switches, switching on station side of transformer banks, and exercise of special care in synchronizing.

(*f*) *Charging Electrolytic Lightning Arresters.*

In cases where noticeable interference is occasioned by charging electrolytic lightning arresters equipped as required in V (*g*), the disturbance can be made less troublesome by charging them during the early morning hours when telephone circuits are little used.

(*g*) *Abnormal Conditions.*

In General Order No. 39, a more specific procedure is outlined than is here given. While the general intent of the present rule is the same, more latitude is given, with the requirement that operating rules shall be developed with a view of minimizing the disturbing effects upon parallel communication circuits.

It is recognized that cases will arise where continuance of service over a faulty power circuit may be of greater importance than the interruption to communication service occasioned thereby and exception is made accordingly to the general rule that faulty power circuits shall not be re-energized for operation until the fault is remedied. It is, of course, contemplated in such cases, that the fault shall be remedied at the first opportunity.

The necessity is evident for having accurate records of abnormal occurrences and the switching incident thereto, for use in investigations to remedy such conditions.

Exhibit.

It is provided in rule IV (*b*) that in the design and construction of Class II power lines, consideration shall be given to the configuration of such lines with a view to minimizing their unbalances and their inductive effects in neighboring communication circuits. Configurations differ widely with respect to their characteristic unbalances and intensities of induction, some arrangements, particularly of twin circuits, giving only 10 per cent or less of the unbalances or induction given by others. In many cases, at little or no additional cost, interference may be materially lessened from what it otherwise would be by giving proper consideration to this matter.

As such information is not always easily available, this exhibit has been prepared to give a brief summary of the Joint Committee's technical data bearing on the subject. Doubtless many cases will arise which will be beyond the scope of the recommendations made in this Exhibit. In such cases a special study may be made. Methods for carrying on such studies are described in the Committee's Technical Reports which are referred to in the Exhibit.

APPENDIX I.

INTERFERENCE NOT COVERED BY RECOMMENDED RULES.

Explanatory Note.—In the rules recommended, the term "communication circuit" is used in a restricted sense as defined in II (*d*) and the power circuits to which the rules apply are limited to those defined in II (*a*) as Class II. While these include the circuits most commonly involved in inductive interference, cases sometimes occur where either the power circuit causing the induction or the signal circuit affected by induction is of a type or character excluded under the above definitions. The Committee has not had an opportunity to make a special study of such cases. In the following the attempt is made to state the governing principles involved, for the assistance of the Commission in considering cases of this character.

(*a*) *Alternating Current Railways.*

Alternating current railway trolley circuits as now generally operated differ radically from other types of alternating current power circuits in that one side of the former is grounded throughout so that they are inherently unbalanced, and moreover, cannot be transposed. To such circuits the provisions of the foregoing rules in general do not apply, and are not so intended.

Where railway circuits of this character are operated, it is necessary to employ special measures in order to prevent inductive interference with neighboring communication circuits. Other than separating the two classes of lines where this is practicable, the most important of such measures can be embodied in the railway construction and should be included in the design of the electrification after a comprehensive study of the requirements of the particular case by the parties concerned. Also, the communication circuits, if metallic, should be properly transposed and otherwise balanced as closely as practicable. The parties should endeavor to agree as to the responsibilities involved and as to further measures to be adopted, if any such are necessary. In the event of failure so to agree the matter should be referred to this Commission.

Note.—This Committee has undertaken no investigation of cases of interference due to alternating-current railways, but as the seriousness of the inductive effects of such railways is recognized, provision is made for co-operation when such cases arise.

(*b*) *Constant-Current Lighting Circuits.*

Care should be taken in the location, design, construction, maintenance and operation of constant-current lighting circuits (both direct-current and alternating-current) to avoid, so far as practicable, inductive interference with communication circuits. In particular every reasonable effort should be made to avoid creating new conditions which would produce such interference, especially where interexchange telephone lines are affected. In cases where such conditions are unavoidable, remedial measures should be employed as may be necessary,

the details of which should be agreed upon by the parties concerned in general accordance with the following provisions:

1. Where necessary, the two sides of the lighting circuit should be run on one pole line within the section where the interference is set up and co-ordinated systems of transpositions applied to the lighting and telephone circuits.
2. Preference should be given to those types of lamps and other equipment which do not introduce high frequency components in the lighting current. The use of incandescent lamps instead of arc lamps is usually advantageous in this respect.
3. Due regard should be given to the insulation and balance of both the lighting and communication circuits. Balance of the lighting circuit requires equalization of the voltages to ground of the two sides of the circuit within the section where the two circuits are in proximity. This necessitates that the circuit be well insulated and in general that the lamps be similarly distributed in the two sides of the circuit with equal numbers of lamps in the two sides between the source of supply and the section of proximity.

NOTE.—It is common practice in city lighting to run single-wire circuits through many lamps in series, scattered widely, instead of carrying the return conductor on the same line, or where the two conductors are on the same line, without balancing their voltages to ground. Both of these features tend to create residuals and to cause severe inductive effects in neighboring signal circuits.

It should be practicable, by care in laying out such lighting circuits, and in locating important telephone lines, such as toll lines which occupy but a few streets, to avoid close proximity between these classes of circuits. In those cases where proximity is unavoidable, it is possible, by running both sides of the lighting circuit close together on the same line, by care in distributing the lamps and by transposing the circuit within the section of proximity, greatly to reduce the residuals.

A considerable difference exists among the various types of lamps used in that arc lamps introduce large harmonics into the lighting circuit, while incandescent lamps produce no appreciable distortion.

The balancing of a lighting circuit can be accomplished in many different ways depending upon the specific conditions. The simplest general procedure is outlined above.

(c) *Power Circuits of Lower Voltages.*

In case of interference with the operation of communication circuits by constant potential alternating-current circuits of voltage lower than the limits specified in the definition of a Class H power circuit, the parties concerned should agree upon remedial measures in general accordance with the rules recommended in this report and should co-operate in applying such measures to the extent that may be necessary, as follows:

1. Where practicable at reasonable expense, the lines should be separated sufficiently to avoid interference.
2. Co-ordinated systems of transpositions should be applied to both classes of circuits within the section where the interference is set up.

3. If practicable, the residual voltage and current of the power circuit should be reduced.
4. Due regard should be given to the insulation and balance of metallic communication circuits.
5. Consideration should be given to the reduction of the high-frequency components of the voltages and currents of the power circuit.

NOTE.—The physical principles upon which the rules as a whole are based apply in case of power circuits of all voltages, the differences being only quantitative in respect to the relative importance of different factors.

(*d*) *Cables.*

In case of inductive interference where either the power circuit or the communication circuit is carried in cable, consideration should be given to the employment of such remedial measures, included in the rules recommended or otherwise as may be reasonably applicable.

In such cases, particular features to which attention should be directed, are: (1) limiting the residual current of the power circuit, (2) balancing the communication circuits if they are metallic, and (3) transposing the communication circuits, if they are metallic and in open wire.

NOTE.—Where cables are used for either power or communication circuits within sections where these two clases of circuits are in proximity, there is, in general, far less liability of interference, and many provisions of the recommended rules are inapplicable. In some cases, however, residual currents in cabled power circuits may cause interference to either open-wire or cabled communication circuits, and open-wire power circuits sometimes cause severe disturbance to communication circuits which are in cable.

(*e*) *Telephone Subscribers' Circuits.*

In case of inductive interference by any electric power circuit with metallic telephone subscribers' circuits (which will usually occur only when the latter are long open-wire surburban loops) the parties concerned should agree upon a plan for avoiding the interference by removal of one of the lines or for mitigating the interference by remedial measures, as the circumstances may require, in general accordance with the recommended rules.

NOTE.—Telephone circuits falling within this class are far more numerous than those included under the definition of communication circuit—II (*d*). Fortunately, subscribers' telephone circuits are not as a rule seriously exposed to the influence of power circuits since they are generally short and are often run partly in cable. When, however, they are exposed, the disturbing effects are relatively more severe on account of the closer proximity of the parallel to the subscriber's station. A parallel involving a subscriber's circuit does not affect so large a portion of the public as a parallel involving an interexchange circuit and on such a basis the former is of less importance. However, this does not justify excluding such circuits from all protection against interference. Consequently, with due regard to the relative importance of the service affected, telephone subscribers' circuits should be afforded such protection as is necessary in general accordance with the principles governing the protection of other communication circuits.

(*f*) *Direct Current Circuits.*

In cases of inductive interference with communication circuits due to constant potential direct current circuits, usually occurring only where grounded railway trolley circuits and telephone circuits are in proximity, adequate remedial measures should be agreed upon and put into effect by the parties concerned. Where telephone circuits are involved, in addition to transposing and balancing such circuits, special consideration should be given: (1) to securing generators and motors having a voltage as free as practicable from high-frequency waves; and (2) to the use of special devices external to the generators, motors and rectifiers which tend to absorb the high-frequency currents and thereby prevent their appearance in the line.

NOTE.—High-frequency components may occur in constant-potential direct-current circuits and occasionally constitute a source of interference. This is particularly true of electrified railway circuits which use a large amount of power. It is therefore provided that effort be made to secure apparatus as free as possible from such high-frequency components and that if necessary, suitable shunt paths be provided to confine these high-frequency components to local circuits.

(*g*) *Other Cases of Interference.*

If any case of inductive interference, not otherwise covered by this report, should be experienced or become imminent, the parties concerned should endeavor to agree upon a procedure for avoiding preferably, or if avoidance be not feasible, for mitigating the interference by applying, to such extent as may be necessary, the measures set forth in this report, or by other means.

APPENDIX II.

LIST OF TECHNICAL REPORTS.

The following is a list of the technical reports which have been prepared in connection with the investigation by the Joint Committee on Inductive Interference. The reports recommended for publication are indicated by an asterisk (*) after the number.

Technical report number.	Subject or title.
1*	General outline of tests to be made at Salinas on parallels between lines of the Sierra and San Francisco Power Company, the Western Union Telegraph Company, the Southern Pacific Company, and The Pacific Telephone and Telegraph Company. (6 pages.) Dated January 6, 1913.
2*	Summary of results of tests at Morgan Hill on parallel between lines of the Coast Counties Gas and Electric Company and The Pacific Telephone and Telegraph Company between Morgan Hill and Gilroy. (8 pages.) Dated February 3, 1913.
3*	A description of the noise standard in use for measuring noise on telephone circuits in terms of a standard unit. (3 pages, 1 drawing.) Dated February 24, 1913.
4*	A description of the instruments and methods used for the measurement of effective values of induced voltages and currents. (2 pages.) Dated February 24, 1913.
5*	A description of apparatus and connections used in measuring line and residual currents and voltages of power circuits. (4 pages, 2 drawings.) Dated February 24, 1913.
6	Tests of the effects of opening the secondary delta of the autotransformer bank at Salinas. (7 pages.) Dated March 31, 1913.
7	Tests of the induction in the block signalling circuits of the Southern Pacific Company paralleled by the Salinas-King City circuit of the Coast Valleys Gas and Electric Company. (3 pages, 1 drawing.) Dated March 31, 1913.
8	Tests of the induction in the telephone circuits of exposure No. 2 at Salinas under normal operating conditions of the power system with particular reference to the effects of grounding and isolating the neutral of the Salinas autotransformers. (15 pages, 1 drawing.) Dated March 31, 1913.
9	Experimental determination of the coefficients of induction for residual currents and voltages in exposure No. 2 at Salinas. (4 pages.) Dated March 31, 1913.
10	Measurements of the harmonics of the neutral current at Salinas. (3 pages, 1 drawing.) Dated March 31, 1913.
11	Investigation of current transformers, ratios and errors due to the use of current transformers under the conditions of the tests. (17 pages, 4 drawings.) Dated April 7, 1913.
12	Formulæ for the computation of electrostatic and electromagnetic induction from power circuits in neighboring communication circuits. (14 pages, 4 drawings.) Dated March 31, 1913.
13.	An investigation of errors in measurements of residual voltage due to the potential transformers used and a discussion of the method of measurement at Salinas. (28 pages, 2 drawings.) Dated September 3, 1913.
14	Comparative tests of the noise in exposed telephone circuits with power on and off the 55,000-volt power circuit of the Sierra and San Francisco Power Company between Guadalupe and Salinas. (7 pages, 1 drawing.) Dated April 30, 1913.

Technical report number.	Subject or title.
15	Supplementary to Technical Report No. 8, differing from the earlier report in that the telephone circuits were shielded. Contains a discussion of transpositions. (22 pages.) Dated June 3, 1913.
16	Tests of induction in telephone circuits exposed to the Coast Counties Gas and Electric Company's 22,000-volt line between Morgan Hill and Gilroy with the power circuit untransposed and open at Gilroy. (4 pages.) Dated April 30, 1913.
17	Tests of the induction in telephone circuits exposed to the Coast Counties Gas and Electric Company's 22,000-volt line between Morgan Hill and Gilroy, before and after installing power-circuit transpositions. (24 pages, 1 drawing.) Dated April 30, 1913.
18.	Tests of the effect, on exposed telephone circuits, of grounding one phase of the Coast Counties Gas and Electric Company's 22,000-volt three-phase delta-connected line. (4 pages.) Dated April 30, 1913.
19	Tests of the combined effect of the Coast Counties Gas and Electric Company's and the Sierra and San Francisco Power Company's circuits on the telephone circuits in the exposure between Morgan Hill and Gilroy. (4 pages.) Dated April 30, 1913.
20	Tests of the effect on the residual voltage of transposing the Coast Counties Gas and Electric Company's 22,000-volt line within the exposure between Morgan Hill and Gilroy. (3 pages.) Dated April 30, 1913.
21	Tests to determine the comparative effect on the noise in the exposed telephone circuits of having the power on and off the Coast Counties Gas and Electric Company's 22,000-volt line between Morgan Hill and Gilroy, and the effect of shielding the telephone circuit under test by grounding other circuits on the lead. (4 pages.) Dated April 30, 1913.
22	Computation of the coefficients of induction from balanced and residual currents and voltages for the telephone circuits of exposure No. 2 at Salinas. (15 pages, 4 drawings.) Dated June 3, 1913.
23	Experimental determination of the coefficients of induction from residual currents and voltages, for the telephone circuits of exposure No. 2 at Salinas—more complete than Technical Report No. 9. (23 pages, 1 drawing.) Dated June 3, 1913.
24	Comparison of computations of Technical Report No. 22 with experimental data of Technical Report No. 23. (10 pages, 6 drawings.) Dated September 3, 1913.
25	Tests of induction in telephone circuits in exposure between Salinas and King City under normal operating conditions, with the neutral of the Salinas autotransformers grounded and isolated. (20 pages.) Dated June 3, 1913.
26	Tests of accuracy of measurement of residual current by certain current transformers. (3 pages, 1 drawing.) Dated June 3, 1913.
27	Tests of induction in telephone circuits in exposure No. 2 at Salinas with the North Beach steam station energizing the Sierra and San Francisco Power Company's line. Supplementary to Technical Reports Nos. 8 and 15, differing in the sources of supply of the power system. (21 pages.) Dated July 14, 1913.
28	Supplementary to Technical Reports Nos. 8 and 15. Voltage lowered 5 per cent at the Guadalupe autotransformers which supply the power circuit. (20 pages.) Dated September 3, 1913.
29*	Determination of impedances of lines, by computations and by measurements—numerous curve sheets and tables. (26 pages, 39 drawings.) Dated May 4, 1914.
30	Tests of induction in telephone circuits in exposure Nos. 1 and 2 at Salinas, with the neutral of the Salinas transformers grounded and isolated. (10 pages.) Dated September 3, 1913.

Technical report number.	Subject or title.
31	Supplementary to Technical Reports Nos. 8 and 15 and more complete. Includes tests with Salinas neutral grounded and isolated and with telephone circuits shielded and unshielded. (29 pages.) Dated September 2, 1913.
32	Supplementary to Technical Report No. 25. (22 pages.) Dated September 3, 1913.
33	Induction in test leads used at Salinas for connecting testing apparatus to the circuits of exposure No. 2, and the effect of such on the measurements of the induction from the exposure. (20 pages.) Dated September 3, 1913.
34	Effect of changes in the insulation resistance of the telephone line on the induction in telephone circuits of exposure No. 2 at Salinas. Also supplements Technical Reports Nos. 8, 15, and 31. (22 pages, 2 drawings.) Dated September 3, 1913.
35	General outline of tests to be made at Santa Cruz on the parallel between lines of the Coast Counties Gas and Electric Company and The Pacific Telephone and Telegraph Company. (4 pages.) Dated July 14, 1913.
36	Induction in telegraph circuits of the Western Union Telegraph Company and the Southern Pacific Company in exposure No. 1 between Salinas and San Jose. (8 pages.) Dated September 3, 1913.
37	Noise tests on telephone circuits radiating from Salinas, with the neutral of the Salinas autotransformers grounded and isolated. (4 pages.) Dated September 3, 1913.
38*	General review of tests at Salinas. Summarizing reports 1, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 22, 23, 24, 25, 26, 27, 28, 30, 31, 32, 33, 34, 36, 37. (52 pages, 1 drawing.) Dated October 13, 1913.
39	General consideration of transpositions and a study of the results to be expected from the application of various transposition schemes to the Santa Cruz-Watsonville exposure. (29 pages, 5 drawings.) Dated December 15, 1913.
40*	Method of measurement of capacitance and conductance unbalances. (1 page, 1 drawing.) Dated December 15, 1913.
41*	Harmonic analysis of alternating current waves by oscillograph and resonant shunt. Comparison of the methods. (27 pages, 3 drawings.) Dated March 16, 1914.
42*	Investigation of the current transformers in use at Santa Cruz, to determine their ratios of transformation and suitability for residual current measurements. (29 pages, 6 drawings.) Dated January 26, 1914.
43	Outline of tests to determine the effect of extraneous current on the intelligibility of telephone conversation. (7 pages, 1 drawing.) Dated March 16, 1914.
44	Induction in the telephone circuits of the Santa Cruz-Watsonville exposure and in the test leads, from sources other than the 22,000-volt line. (12 pages.) Dated March 16, 1914.
45	Induction in the telephone circuits of the Santa Cruz-Watsonville exposure under commercial operating conditions, with the original transpositions in both power and telephone lines. (15 pages.) Dated March 16, 1914.
46	Supplementary to Technical Report No. 39. A study of additional transposition schemes for the Santa Cruz-Watsonville exposure. (12 pages, 2 drawings.) Dated May 4, 1914.
47	Computation of the coefficients of induction for balanced and residual currents and voltages for the Santa Cruz-Watsonville exposures. (13 pages, 2 drawings.) Dated May 4, 1914.
48	Experimental determination of coefficients of induction in the Santa Cruz-Watsonville exposure, with the original transpositions. (42 pages.) Dated May 4, 1914.

Technical report number.	Subject or title.
49	Further experimental determination of coefficients of induction for balanced voltages, in the Santa Cruz-Watsonville exposure, with the original transpositions. (13 pages.) Dated May 4, 1914.
50*	Study of the influence of various transformer connections and flux densities on the third harmonic and its multiples in a three-phase circuit. (18 pages, 2 drawings.) Dated October 9, 1914.
51*	Residual voltage due to the line unbalance of power circuits isolated from ground. Effect of circuit configuration transpositions and frequency. (69 pages, 38 drawings.) Dated September 30, 1916.
--*	Memorandum supplementing Technical Report No. 51. (2 pages.) Dated February 28, 1917.
--*	Memorandum supplementing Technical Report No. 51. (2 pages, 1 drawing.) Dated July 16, 1917.
52*	Residuals produced by a ground on one phase of a normally isolated three-phase system. (29 pages, 2 drawings.) Dated July 28, 1915.
--*	Memorandum supplementing Technical Report No. 52. (4 pages.) Dated July 3, 1917.
53	Investigation of current transformers—San Fernando. (7 pages, 1 drawing.) Dated July 29, 1915.
54*	San Fernando-Somis parallel. Experimental determination of coefficients of longitudinal induction at 50 cycles. Effect of transpositions in power circuits. (30 pages.) Dated October 1, 1915.
55*	Experimental determination of coefficients of induction from residuals at telephonic frequencies—Effect of admittance unbalance. San Fernando-Somis parallel. (26 pages, 6 drawings.) Dated January 7, 1916.
56*	Determination of coefficients of induction in a short section of the San Fernando-Somis parallel. Measurements and computations. Effect of telephone transpositions. (41 pages, 6 drawings.) Dated February 10, 1916.
57	Determination of coefficients of transverse induction from residuals at telephonic frequencies in a short section of the San Fernando-Somis parallel. (8 pages, 3 drawings.) Dated February 14, 1916.
58*	Investigation of potential transformers for residual voltage measurements. (42 pages, 4 drawings.) Dated April 14, 1916.
59*	Relation of triple harmonic residuals in a transmission line to the magnetic density in connected transformer banks. Effect of the line characteristics. (61 pages, 14 drawings.) Dated September 6, 1916.
60*	Triple-harmonic residuals as affected by certain types of three-phase star connection of transformers. (24 pages, 4 drawings.) Dated July 26, 1916.
61*	Measurements of residual voltages and currents of several transmission systems. (29 pages, 1 drawing.) Dated July 29, 1916.
62*	Double-frequency voltages and currents in a three-phase transmission line. (13 pages, 1 drawing.) Dated March 18, 1916.
63*	Standard forms for recording data and computations. (22 pages.) Dated March 8, 1916.
64*	Computation of induction between parallel power and communication circuits. (46 pages, 1 drawing.) Dated August 4, 1916.
65*	Coefficients of induction for communication circuits paralleled by three-phase power circuits. Variation with relative position and configuration. (54 pages, 214 drawings, 92 tables.) Dated January 6, 1917.
66*	Co-ordination of transposition systems for power and telephone circuits. (63 pages, 19 drawings.) Dated January 6, 1917.
67*	Notes on the transposition of power circuits, and private telephone circuits. (9 pages, 3 drawings.) Dated August 14, 1917.

Technical report number.	Subject or title.
68*	Effect of protective ground wires of power lines on induction in parallel communication circuits. (7 pages, 1 drawing.) Dated June 28, 1917.
69*	Relation of currents in terminal apparatus of telegraph circuits to induced voltages and location of parallel. (8 pages, 2 drawings.) Dated July 19, 1917.
70*	The relative importance of the volt-mile (electric induction) and the volt (magnetic induction) in causing interference with telephone circuits. (10 pages, 1 drawing.) Dated August 17, 1917.
71*	The influence of wave-form on the detrimental effect of induction. (11 pages, 1 drawing.) Dated August 10, 1917.

The following reports, technical in character, were prepared at the request of the Joint Committee, but outside of its organization:

Tests to determine the effect of extraneous current of single frequency on the intelligibility of a telephone conversation. (13 pages, 14 drawings.) Dated December 22, 1914. Laboratory investigation by Engineering Department of American Telephone and Telegraph Company.

Tests to determine the effect of extraneous single frequency current on telegraph transmission. (40 pages, 29 drawings.) Dated September 14, 1916. Joint laboratory investigation by engineers of the Western Union Telegraph Company, the Postal Telegraph-Cable Company and the American Telephone and Telegraph Company.

The development of balance of telephone circuits. Practice of telephone companies in balancing their lines and apparatus as a means of reducing induction from foreign circuits and other telephone circuits. (61 pages, 20 drawings.) Dated June 15, 1915. Submitted by A. H. Griswold on behalf of the telephone interests.

APPENDIX III.

COMMENTS ON THE REPORT OF JULY 7, 1914, BY THE JOINT COMMITTEE ON INDUCTIVE INTERFERENCE TO THE RAILROAD COMMISSION OF THE STATE OF CALIFORNIA.

The investigations conducted since the issuance of the preliminary report in 1914 have greatly extended the detailed knowledge of the various factors affecting inductive interference, and have disclosed a few misstatements in the former report. The new matter is contained in Technical Reports Nos. 51 *ff.*, listed in Appendix II. The purpose of this appendix is to comment on certain statements of the preliminary report and to correct misstatements.

In Appendix I of the former report in the next to the last paragraph (on page 21)*, investigations are mentioned, to be conducted by the American Telephone and Telegraph Company, Western Union Telegraph Company and Postal Telegraph-Cable Company. The reports upon these investigations have been received and are listed in Appendix II of the present report.

In Appendix II of the former report under "3. Means for Preventing or Reducing Residual Voltages and Currents"—fifth paragraph, line 5, *ff* (beginning in the sixth line from the bottom of page 28)* it is stated that "With a horizontal arrangement of conductors, the capacities to ground are more nearly equal than with the triangular or vertical arrangement." As shown in Technical Report No. 51 (see also the exhibit of Part III of this report), the fact is that lines having their conductors in a plane, vertical or horizontal, present the worst unbalances of capacitances to ground experienced with ordinary configurations. Briefly, the triangular configuration is in general the best balanced; vertical and symmetrical horizontal configurations are very nearly alike with much greater unbalances than the triangular, and a little better than the unsymmetrical horizontal, which is the worst.

With respect to the remainder of the same paragraph, investigation has shown that the "electrostatic capacities" *are* "the controlling factors in determining the residual voltage and current of an isolated system under normal operation" with proper insulation; and that "properly spaced transpositions" *are* "substantially effective," thus confirming the statements previously made.

It should be noted that with a grounded neutral (see second paragraph of page 29) a residual current exists corresponding to the residual voltage of the isolated system, and is similarly controllable by transpositions. This matter is discussed in Technical Report No. 51.

In Appendix III of the former report, under "1. Effect of Transpositions in Reducing Induction," fourth paragraph, the words "series impedance" should be added before the word "capacity" in line 10 (the 11th line from bottom of page 32),* so the sentence will read "The voltage induced along the conductors of the telephone circuit and the induced voltage to ground would be present but would not be

*Page references are to edition of report published by the California State Printing Office, 1914.

effective in producing any voltage between the conductors of the telephone circuit, provided the series impedance, capacity and leakage to ground of each side of the telephone circuit were equal.''

In the same Appendix, in the next to the last paragraph of ''1. Effect of Transpositions in Reducing Induction'' (page 33)* the word ''not'' was omitted after ''can.'' The first sentence should read ''If the communication circuit has a ground return, it can not be transposed and the power circuit transpositions alone (referring to transpositions) will be effective in reducing interference arising from balanced currents and voltages.''

With the foregoing changes, the discussion given in the preliminary report is considered correct, though much more complete discussions of various of its topics are to be found in the Technical Reports.

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*Page references are to edition of report published by the California State Printing Office, 1914.

APPENDIV IV.

BIBLIOGRAPHY.

In the course of its investigation the Committee has collected numerous references to the published literature of subjects related to its work. A list of such references which deal directly with inductive interference is given below for the benefit of those interested in further study.

Many discussions on related subjects, such as transformer connections and design, switches and switching, protective devices, wave-form of electrical power apparatus, line construction, telephone apparatus, etc., may be found in textbooks, proceedings of societies and periodicals. No attempt has been made to include such references here.

It will, of course, be understood that the Committee in no way expresses opinion respecting statements made in the discussions listed, by referring to them here.

A list of references concerning the effect of transformers on the wave-form of currents and voltages, as influenced by magnetic saturation, is given in Technical Report No. 59; and a list of references on the computation of electric induction in Technical Report No. 64.

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Inductive Disturbances as Affecting Telephone and Telegraph Lines. P. J. Howe. Electrical World, May 31, 1913.

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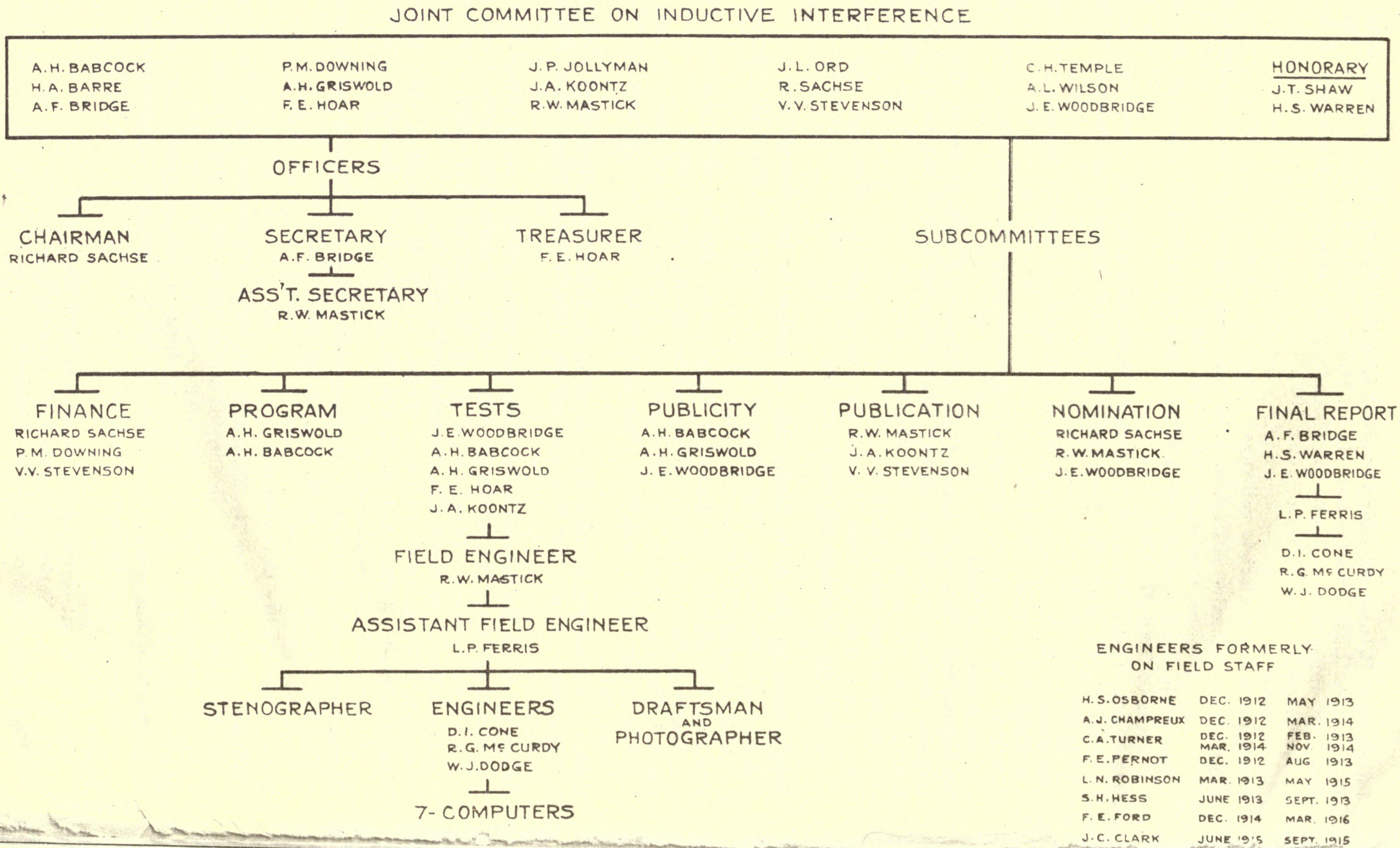
ABBREVIATIONS:

A. I. E. E.—American Institute of Electrical Engineers.
N. E. L. A.—National Electric Light Association.
Elek. Zeit.—Elektrotechnische Zeitschrift.

APPENDIX V

ORGANIZATION CHART



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